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Toward an Integrated Regional Research Program on Global Change and the Nation's Major Grasslands: Second Annual Report

Great Plains Regional Center-NIGEC

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TOWARD AN INTEGRATED REGIONAL RESEARCH PROGRAM ON GLOBAL CHANGE AND THE NATION'S MAJOR GRASSLANDS

Second Annual Report

GREAT PLAINS REGIONAL CENTER FOR GLOBAL ENVIRONMENTAL CHANGE

National Institute for Global Environmental Change
U.S. Department of Energy

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University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources

TABLE OF CONTENTS

TITLE **PAGE**

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Great Plains Regional Center Director's Report
1994-95
William E. Easterling, Director

The Great Plains Regional Center (GPRC) began its second year of operation in 1994. Situated in the Institute of Agriculture and Natural Resources at the University of Nebraska-Lincoln, the GPRC is administered by Director William E. Easterling, Associate Director Blaine L. Blad and Project Assistant Jan Schinstock. The GPRC office is located in the Department of Agricultural Meteorology where the Director and Associate Director maintain academic appointments.

The GPRC focuses on the region encompassed by the states of Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North and South Dakota and Wyoming. Colorado is shared with the South Central Regional Center. Research pertaining to the southern Great Plains (Oklahoma, Texas, New Mexico) is of relevance to the GPRC, but is coordinated with the South Central Regional Center.

The Great Plains region encompasses the nation's largest grassland biome. The region produces nearly a quarter of the nation's agricultural crops and livestock. Also, it is typified by strong climatic gradients, with annual precipitation of over 900 mm on the eastern edge to less than 200 mm on the western edge. Its interior continental position produces large interseasonal extremes of temperature and precipitation, and the frequency of extreme events, especially droughts, is higher in the Great Plains than in regions nearer large water bodies. Agriculture and other ecosystems in the region are known to respond nonlinearly to climate forcing. Small changes in already marginal climate conditions for many ecosystems produce disproportionately large impacts. The deep loess soils typical of the Great Plains store large amounts of carbon in the form of soil organic matter. Moreover, observed changes in the composition and location of ecotones, changes in the extent and intensity of land use, coupled with periodic climate variations have strongly influenced the cycling of nutrients and net exchanges of carbon in the Great Plains. Finally, several climate models predict severe climate changes in mid-latitude continental interiors relative to global average changes. These above factors argue for a research program that focuses on the potential consequences of climate change for the Great Plains region.

The remainder of this report will: (1) summarize the conceptual framework of the GPRC's research program and corresponding research thrusts; (2) summarize the FY94 grant competition and provide a synopsis of all projects funded in 1994, organized by research thrust; (3) summarize important outcomes of the 1994 first annual GPRC PIs workshop and other activities aimed at research integration; and (4) outline future activities of the GPRC. Appended to this report are the detailed FY 94 progress reports for each of the projects funded by the GPRC.

GPRC RESEARCH FRAMEWORK AND THRUSTS

The primary goal of the GPRC is to develop a "bottom-up" regional research program that provides basic understanding of the implications of climate change for the Great Plains to complement the efforts of the U.S. Department of Energy to develop integrated assessment policy tools. The term bottom-up is defined here as research that begins *in situ* at the process level and, through scaling and aggregation of results, is extrapolated to derive regional estimates of response to environmental forcing. The regional estimates are meant to be comparable across NIGEC regions. The research scope of the GPRC will be "end-to-end," identifying and, where possible, quantifying explicit linkages between climate change, basic biophysical and ecological processes (e.g., hydrologic properties, plant physiology and water relations, surface energy exchanges), managed and unmanaged ecosystem function (e.g., biogeochemical cycling, net primary productivity, adaptive capacity), and socioeconomic activity (impacts on gross regional product and net social welfare, institutional response) including feedback mechanisms (e.g., climate change-induced changes in landuse and corresponding land-cover with feedbacks to soil organic matter and trace gas emissions). As such, the GPRC research program will provide an alternative to reduced-form climate change damage functions for estimating the impacts of climate change within integrated assessment models.

The major components of the GPRC's research program are shown schematically on figure 1. The figure begins with the development of appropriate regional scenarios of climate change leading to process studies and regional estimates of net carbon exchanges between the atmosphere and the region's managed and unmanaged ecosystems; the chain of causality also leads from climate change scenarios and process studies to the estimation of impacts on those ecosystems and ends with an economic assessment of the regional consequences of climate change and efforts to adapt to and mitigate such change. Land use change is seen as linking adaptation with processes of net carbon exchange. Methodological research such as, for example, development of techniques for scaling and aggregation of model results, is embedded throughout the framework.

The above framework was the foundation for the 1994 GPRC research thrusts which, in summary form, were: *(1) the quantification of the consequences of climate change for managed and unmanaged ecosystems of importance to human activity in grasslands, including assessment of the adaptive capacity of such ecosystems and feedbacks, if any, to the next thrust; and (2) the measurement and modeling of net exchanges of carbon dioxide and other energy-relevant radiatively-active trace gases between terrestrial ecosystems and the atmosphere, particularly in grasslands.* An additional research thrust focusing on the detection and attribution of greenhouse-forced climate change was deleted last year, although final reports from projects addressing that thrust are included in this year's set.

FY94 GPRC GRANT COMPETITION

The GPRC conducted its second grant competition over the fall-winter of 1993-94 in order to allocate research funds for FY94. Funds for new projects were extremely limited since most of the GPRC's projects were begun the previous year. Thirty-two proposals were received from twenty institutions in or near the Great Plains region. Fourteen of these proposals were second- or third-year continuation proposals. Of the remaining eighteen new proposals submitted, four were funded. All proposals received were peer reviewed by mail and by a scientific advisory panel for scientific merit and were submitted to DOE for a test of relevancy to agency research priorities. Research money was awarded to eighteen proposals, with approximately 36% of the funds going to University of Nebraska-Lincoln (UN-L) investigators and 64% going to investigators at other institutions.

The total allocation of research funds to the 18 projects was $1,467,300, leaving $38,001 in the Director's Fund for FY94. The Director's Fund was used to: (1) conduct the 1994 GPRC PIs Workshop in Lincoln (summarized below); (2) to fund a seed project by J. Antle of Montana State University to develop an economic modeling framework to be expanded into a major integrated assessment proposal for FY96; and (3) to support a meeting of GPRC investigators to coordinate development of alternative scenarios of climate change for impact analysis.

SYNOPSIS OF CURRENT PROJECTS

A brief synopsis of current projects is divided into the two research thrusts of the GPRC. Some projects overlap thrusts and are discussed accordingly. All projects discussed below are described in detail in the progress reports that follow. Unless otherwise noted, all projects discussed below received initial actual funding in December of 1993--thus, progress reported was for 18 months of work.

Thrust 1: Impacts of Climate Change

Process Studies. Field-based process studies are being conducted better to understand basic interactions of climate with physical and biological systems in the Great Plains. Such understanding will, in some cases, provide better model constructs for estimating impacts of climate change. In their second year of a three-year project, Blair and colleagues at Kansas State University are examining the effects of altered soil moisture and temperature on basic biological properties of and processes in prairie soils (e.g., soil organisms, organic matter storage and turnover, nutrient retention) by reciprocal transplanting of intact soil cores between different climate regimes to then study soil response to the new climate. *An important result to date is the observed rapid decline of potentially mineralizable nitrogen in xeric soils transported to relatively more humid climates.*

In their second year of a three-year project, Rundquist and colleagues at the University of Nebraska-Lincoln are studying highly dynamic lake/wetland systems in the Nebraska Sand Hills to establish baseline conditions (e.g., relationships between climate, groundwater and biomass, and energy and carbon fluxes), against which "environmental variance" can be determined using a combination of *in situ* climate and hydrologic data and remote sensing imagery (Landsat-TM and MSS). Linkage of imagery of biomass with trace gas fluxes in prairie wetlands being measured by Verma and colleagues (reported below) is also being attempted. *An important result to date is the development of relationships between changes in remotely-sensed lake surface area, the timing of precipitation and interseasonal rates of evapotranspiration. Some results of area measurements, for 130 lakes from 42 Landsat-MSS scenes over 15 years, include mean sizes that range from <5 to 870 acres and standard deviations that range from 3 to 60 acres. The investigators have documented the fact that the lakes and the groundwater systems function in concert with one another.*

In their second year of a two-year project (with a proposed three-year follow-on study under development), Hoagland and colleagues at the University of Nebraska-Lincoln are studying genetic markers among diatom floras along a zonal temperature gradient in the Great Plains to understand the adaptability of such species to different climate regimes in order to understand how climate change may affect prairie aquatic systems[1]. *An important result to date has been the success in separating distinct diatom clones by location along the latitudinal transect. These observed clusters are confirmations of laboratory temperature manipulations. Temperature ranges for optimal growth of different clones were established.*

Climate Scenarios for Impacts analysis. Alternative methodologies for the development of climate change scenarios for use in the conduct of impact analyses are an important component of Thrust 1. Based on recommendations from the first annual PIs workshop, the GPRC is coordinating an intercomparison of climate scenario generation techniques. Scenarios generated by a small selection of those techniques are being coordinated by the GPRC for distribution to other GPRC projects to use in estimating climate change impacts.

In the second year of a three-year study, Mearns and colleagues at the National Center for Atmospheric Research and the University of Nebraska-Lincoln are developing and manipulating regional climate models "nested" within general circulation models (GCMs) to produce high-resolution climate change scenarios in order to test the importance of spatial and temporal scale in estimating the agricultural impacts of climate change. *Important results to date include the successful replication of the 1988 summer precipitation anomaly in the interior U.S. with the nested climate model and the finding that resolving climate data inputs*

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[1] This study was initiated in 1993 to develop a basis for detecting climate change and for assessing aquatic carbon cycling in the Great Plains. After de-emphasis of detection studies by DOE, the implications of the work for estimating impacts of climate change on higher aquatic trophic levels allowed continuation of the project as important and necessary preliminary work to a follow-on modeling study.

at smaller grid box scales than GCMs vastly improve agreement between modeled estimates of crop yields and observed crop yields, although highly resolved soil data inputs do not seem to matter.

In the second year of a three-year study, Palecki and colleagues at the University of Nebraska-Lincoln, University of Delaware and Rutgers University are using a "calendar shift" method to generate climate warming scenarios. By shifting each month either forward or backward, depending on the natural seasonal progression of warming/cooling, they have developed a new monthly distribution of daily temperatures and precipitation. A water balance model is being computed with the seasonally-adjusted climate to examine impacts of such climate scenarios. *An important result to date has been the demonstrated close agreement between the calendar-shifted climate for a test site (Gothenberg, Nebraska) and the nearest grid point computation of the equilibrium climate with 2XCO_2 radiative forcing[2] from the Canadian Climate Centre's GCM.* Such provides comparable climate change scenarios to GCM-based scenarios that also preserve realistic intraannual serial correlations.

In the second year of a three-year study, Bogardi and colleagues at the University of Nebraska-Lincoln and the University of Arizona are developing and testing a stochastic technique for downscaling climate model-simulated atmospheric circulation patterns to derive local hydrologic quantities for impact analysis. They are relating simulated with observed circulation patterns; observed circulation patterns are then related to local surface climatological conditions. Impact analysis is performed by relating changes in surface climate from greenhouse warming to the Palmer Drought Severity Index to estimate drought frequency and intensity. *Important results to date show clear differences in average heights of pressure fields between 1xCO_2 (historic and modeled) and 2XCO_2 (modeled only) circulation patterns in Nebraska. Precipitation in the 2XCO_2 case was increased relative to 1XCO_2 but the variability was increased too, meaning fewer high-rainfall events.*

Two studies pertaining to climate modeling but less directly related to the specific research thrusts of the GPRC were supported. In the second year of a three-year project, Han and Welch at the South Dakota School of the Mines are investigating the relationships between cloud cover characteristics and ecosystem types. Also, the relationship between cloud droplet radii and the Net Difference Vegetation Index (NDVI) is studied across the Great Plains. Such information will help establish the possible interactions of climate change, cloud cover and ecosystem response on a large scale. *Important results to date include the findings that: (a) NDVI is directly related to cloud radii meaning that clouds form with larger droplet sizes over vegetated surfaces than nonvegetated surfaces; and (b) the relationship between aerosols, cloud droplet radii and albedo is not yet detectable for most regions globally.*

In the second year of a two-year study, Chen and Tribbia at Iowa State University and the National Center for Atmospheric Research (NCAR) respectively are studying the effects of Pacific sea-surface temperatures (SST) on interannual and interdecadal variability of winter atmospheric circulation using upper air observational data and post-WWII time series of circulation patterns in the NCAR general circulation model (CCM). *An important result to date is the finding that the global relative angular momentum (RAM) is a strong indicator of interannual variation of atmospheric circulation and also coincides with the Southern Oscillation Index with embedded SSTs. Inclusion of such components in the NCAR CCM enhances climate variability under the 2XCO_2 scenario.*

Modeling Impacts of Climate Change. Modeling approaches are being used in a number of studies to synthesize results of process studies and to estimate the regional scale consequences (impacts and adaptations) of climate change on some aspect of the natural resource base of the Great Plains. Although

[2] The term "1XCO_2" refers to a GCM representation of the equilibrium climate with greenhouse gas radiative forcing at current ambient levels. The term"2XCO_2" refers to a GCM representation of the equilibrium climate with CO_2 concentrations increased to a level that serves as a proxy for a doubling of all greenhouse gas (CO_2, CH_4, O_3, CFC, etc.) concentrations above preindustrial levels.

all of the studies with a regional modeling component are mentioned in this section, some of the studies focus primarily on Thrust 2 and are only identified here for further discussion under Thrust 2.

The Mearns and colleagues project described above is providing crop model estimates of the effects of high-resolution scenarios of climate change on productivity. In the second year of a three-year project, Brandle and colleagues at the University of Nebraska-Lincoln and Iowa State University are examining the influence of shelterbelts on micro- and meso-scale climate in the Great Plains. The practical importance of such work is the insight it provides into the ability of artificial and natural riparian shelterbelts to protect crops and habitat under conditions of climate change. Mechanistic modeling combined with direct field observations of microclimate in a fully replicated experimental shelterbelt system is used better to understand shelterbelt influences on crop microclimate. One of the mechanistic crop growth models used in the Mearns and colleagues project is used here to examine the influence of shelterbelt-modified microclimate on crop productivity under assumptions of climate change. A modified forest gap model is being used to estimate the change in habitat in riparian forest systems as a first step in tracing the effects of climate change on species diversity in such systems. An economic input-output model is being modified to estimate the economic costs/benefits of shelterbelts with climate change based on crop modeling results. *Important results to date include the preliminary model finding that shelterbelts reduce regional evaporation rates by reducing near-surface turbulence. Also, crop productivity in shelter is not nearly as negatively affected by climate warming and drying as productivity in open field conditions. A forest dynamics model called "Seedscape" has been developed to predict species composition in Great Plains riparian forests; validation of the model and development of an animal response component have begun. Several scenarios have been tested to estimate the economic value of shelterbelts under the current Great Plains climate--optimally sized shelterbelts were found to provide net positive economic benefits, despite lost cropland to trees.*

Using the same crop growth model as Brandle and colleagues, Dyke and colleagues at Texas A & M University, Battelle-Pacific Northwest Laboratories and the University of Nebraska are in the first year of a three-year study examining the feasibility of substituting biomass fuel crops in place of existing crops in the Great Plains. In addition to estimating the agronomic and economic feasibility of biomass production under climate change, the crop model is coupled with a runoff model to provide comparisons of effects of existing cropping systems versus biomass production systems on regional runoff. *An important early result is that biomass (switchgrass) reduces erosion and runoff, but does not fare as well under a replay of the 1930s climate as traditional crops of the region, no account taken of elevated CO_2 or adaptation.*

In the first year of a three-year project, Neilson and colleagues at Oregon State University and Colorado State University are linking a watershed model (MAPSS) with a landscape-scale ecosystem process model (CENTURY) in order to understand regional changes in energy and water fluxes resulting from climate change in a mixed grassland-shrub-tree landscape in the Great Plains. The prototype modeling scheme is being developed with data from Wind Cave National Park in western South Dakota. *An important result to date is the successful validation of the MAPSS model with data from southwestern Idaho. The preparation of environmental data sets for Wind Cave National Park is nearly complete.*

The CENTURY ecosystem model is being used in two other projects summarized under Thrust 2 in order to determine soil organic matter (SOM) dynamics between different vegetation classes (see Tieszen and colleagues below) and among different land management strategies (see Elliott and colleagues below).

In the first year of a three-year project, Malanson and colleagues at the University of Iowa are examining basic properties regulating the scaling of the results of spatially explicit ecological models to surrounding landscapes in the Great Plains. Emphasis is given to the interactions of climatic gradients (temperature and moisture), seed dispersal and model grid cell size in determining species composition with a dynamic forest simulation model tailored to mid-continent locations. *An important result to date is that modeled species diversity across a large region is low in the absence of a climate gradient and increases* *dramatically with the introduction of only a slight gradient and is little affected by a still stronger climate gradient.*

Thrust 2: Measuring and Modeling Net Carbon Exchange

The measurement and modeling of processes of net carbon exchange in key Great Plains ecosystems is the second research thrust of the GPRC. Four projects are funded under this thrust, two of which are field-based process studies, the third is an integrated process and modeling study and the fourth is purely a modeling assessment.

Process Studies. In the second year of a three-year project, Verma and colleagues at the University of Nebraska-Lincoln, Colorado State University and the National Center for Atmospheric Research are examining surface fluxes of carbon dioxide and methane in mid-latitude prairie wetlands. Concurrent micrometeorological (eddy correlation) and chamber flux measurements are being made to relate fluxes with their underlying biophysical controls on a Nebraska Sand Hills wetland (near Valentine, NE). *Important results to date include partitioning of typical diel courses of clear day surface energy balance components into net radiation, heat storage in the water-sediment layer, sensible heat flux, and water vapor flux. Micrometeorological measurements found the wetland beginning the growing season as a source of CO_2 and changing rapidly to a sink until senescence when exchange rates approached zero. They also found that methane flux increased during the course of the growing season before declining to near zero with senescence. Significant diurnal differences in methane flux were found, with fluxes being significantly higher and more variable during the daylight hours than during the nighttime hours. Nighttime fluxes appear to correlate strongly with changes in sediment/water temperature. Chamber measurements of CO_2 flux confirm the patterns seen in the micrometeorological measurements, plus they suggest the fluxes may be related to canopy foliage area and water column temperatures.*

In the first year of a three-year project, Ham and Knapp at Kansas State University are examining how changes in environmental and biological forcing and land management (grazing, burning) may regulate fluxes of carbon, water and energy from a tallgrass prairie (Konza Long Term Ecological Research site). A suite of micrometeorological measurement techniques initially will be used before settling on the technique that seems best suited to conditions. *An important result to date is the establishment of measurement sites and the assemblage of instruments to begin measurements over the summer of 1995.*

Modeling Studies. In the second year of a three-year project, Tieszen and colleagues at Augustana College, Iowa State University, University of Kansas, Colorado State University, EROS Data Center and the National Center for Atmospheric Research are examining carbon isotopic fractionation signatures of C_3 and C_4 plants in grassland ecosystems to determine whether or not such ecosystems are currently in a steady state with climate. Information generated from the isotopic fractionation analysis will be integrated with the CENTURY ecosystem model to examine carbon fluxes from various soil organic matter fractions under different land management schemes. Additionally, AVHRR-based vegetation indices are used to classify C_3 and C_4 vegetative cover classes to make regional assessments of net carbon exchanges based on the isotopic and modeling analyses. *Important results to date include the finding that, when examined independently, STATSGO and isotope data show that similar environmental variables (e.g., climate, soil texture) determine the proportional contribution to primary production, thus providing validation of the isotopic methodology. Moreover, from isotopic fractionation analysis it was found that the grassland soils studied here are not in a steady state with the atmosphere in terms of contribution to primary production, mainly because of anthropogenic influences. Yet, the unexpectedly high contribution of C_3 species to production cannot be totally explained by anthropogenic influences.*

In the second year of a three-year study that complements the work of Tieszen and colleagues, Elliott and colleagues at Colorado State University are examining the interactive effects of climate, elevated CO_2 levels and land management on soil organic matter (SOM) dynamics in the central U.S. wheat and maize production regions using the CENTURY ecosystem model. Analyses are structured to permit analysis of effects of existing cropping practices (tillage, crop rotation) on SOM dynamics, the effects of climate change on such, and the determination of the management practices under climate change and elevated CO_2 levels that optimize SOM accumulation. *An important result to date is the conclusion that changes in land management practices combined with higher CO_2 concentrations have a greater influence on SOM accumulation than changes in climate.*

Other Projects

Two projects with the goal of detecting and attributing climate change resulting from anthropogenic radiative forcing were completed this year. Though, work in this area is no longer emphasized by NIGEC and will not be supported further by the GPRC, important understanding was gained in these initial efforts. Gosnold and Todhunter at the University of North Dakota have studied transient perturbations in the geothermal gradient in connection with surface temperature observations along a north-south transect of observing points with the goal of detecting changes in the gradient that may signal greenhouse warming. *An important result to date is that borehole temperature profiles across the transect correlate strongly with latitude as indicated by climate model predictions of greenhouse warming.*

Lillesand and colleagues at the University of Wisconsin-Madison examined the timing and extent of mid-latitude lake ice break-up as an indicator of climate change using remotely sensed imagery with a numerical thermodynamic lake ice model. *An important result to date stemming from sensitivity analysis of the model is that the ice-off date is more sensitive to air temperature than the ice-on date and that either is more sensitive to temperature warming than cooling.*

SUMMARY AND RECOMMENDATIONS OF FY94 GPRC PIs WORKSHOP

The GPRC hosted its first annual workshop of funded PIs September 29-30, 1994 in Lincoln. The main objective of the workshop was to facilitate collaboration among PIs leading to exchanges of data and information among projects as a first step toward integrating broad areas of research. The workshop was divided into two parts. The first part consisted of short plenary presentations of each of the funded projects. The second part consisted of breakout discussions focusing on four major research topics under the umbrella of the GPRC's research program: (1) biogeochemical cycling (Shashi Verma, chair; Jay Ham, rapporteur); (2) development of climate scenarios for impact analysis (Linda Mearns, chair; Michael Palecki, rapporteur); (3) managed and unmanaged ecosystem impacts (Ted Elliott, chair; David Guertin, rapporteur); and (4) scaling of data and model simulations (George Malanson, chair; Rollin Hotchkiss, rapporteur).

Each of the breakout groups was asked to focus on one or more of the following tasks: (1) identification of major strengths and gaps in the GPRC research program; (2) identification of specific potential interactions between one or more projects/topical areas; and (3) recommendation of specific new research topics to incorporate into the GPRC research program. A summary of discussion of each of the four breakout topics follows (Appendices I-A, I-B, and I-C contain rapporteurs' records of discussion for each of the groups, exclusive of the scaling group). It should be noted that while the scaling group discussions are summarized below, there is no record of discussion for the scaling group since most such issues are pervasive of the other three topical groups and thus were inserted into the other three group reports to avoid redundancy.

Biogeochemical Cycling Group. The common interest of the group was the conduct of field experiments to examine how key biogeochemical processes may interact with climate change in the Great Plains with the goal of understanding biophysical regulators of the biology, hydrology and trace gas dynamics of principal ecosystems. Among the strengths of the GPRC program in this regard are: (1) the integration of climate modelers with process-level scientists; (2) the conduct of net carbon exchange work at different scales using different measurement and modeling methodologies; and (3) the synergy the GPRC funding provides to ongoing work supported by other funding agencies, particularly on recognized research facilities (e.g., LTER sites).

Among the gaps in the GPRC program with respect to biogeochemical cycling are: (1) an imbalance of funded research that favors modeling efforts over measurement and experimentation; (2) the lack of a dynamic land use/land cover classification for the Great Plains for scaling *in situ* process studies; and (3) poor linkage between hydrologic models and carbon cycle/ecosystem models. The group recommended that high priority be assigned to the filling of those gaps in future GPRC grant competitions.

Several potential interactions among PIs conducting biogeochemical cycling work within the Great Plains region were identified. Examples include: (1) the application of stable carbon isotope analysis (see Tieszen and colleagues, this report) to grasslands (see Ham and Knapp, this report) and wetlands (see Verma and colleagues, this report); (2) comparison of trace gas flux measurement techniques (Ham and Knapp, Verma and colleagues, this report); and (3) application of carbon cycle/ecosystem models (see Neilson and colleagues, Elliott and colleagues, Tieszen and colleagues, this report) to soil core analyses (Blair and colleagues, this report).

Climate Scenarios Group. The development of a set of credible scenarios of climate change for application to impact analyses is essential to integrating individual impact studies. The group gave primacy to the need to assemble such a set of scenarios utilizing the work underway in three GPRC projects: (1) the down scaling of atmospheric circulation patterns to surface climate series through statistical associations (Bogardi and colleagues, this report); (2) the "nesting" of regional climate models within general circulation models (Mearns and colleagues, this report); and (3) the shifting of the annual seasonal cycle, termed "calendar shifting," to create a new climate series. A strong recommendation of the group was for the GPRC to facilitate coordination of outputs from those three projects to create a package of usable alternative climate change scenarios to conduct impact model intercomparisons.

The group identified a major research priority concerning the development and use of climate change scenarios for impact analysis: the need to conduct sensitivity analysis with impact models to determine a range of possible outcomes in order to account for the high level of uncertainty and possibility of surprise inherent in the climate change scenarios.

Managed and Unmanaged Ecosystem Impacts Group. Recognizing the broad charter of the impacts group, a framework was developed to organize a discussion of research gaps and needs under the ecosystem impact headings of: (1) productivity; (2) carbon storage; (3) water quality and availability; and (4) biodiversity. The framework identified major research approaches, key underlying processes, driving variables and necessary data bases for each of the impact headings.

Major research gaps identified under productivity included the need: (1) for adaptation of forest production models to represent riparian forest systems in the Great Plains; (2) for development and manipulation of models of various aspects of animal (livestock and wildlife) response to change in climate and habitat; (3) to conduct process studies of plant growth response to climate change with higher atmospheric CO_2; and (4) to examine pest response to climate change and possible implications for plant productivity. The group stressed the need for development of appropriate data bases for virtually all aspects of impact analysis.

Major research gaps identified under carbon storage included the need: (1) to develop stronger linkage between remotely sensed imagery and process studies of biophysical controls of net carbon exchange processes *(Director's note: this obviously overlaps with the biogeochemical cycling group recommendations and is addressed below)*; (2) to develop mass balance equations for below ground carbon storage as affected by climate change and higher atmospheric CO_2 *(Director's note: this recommendation is addressed below)*; and (3) to understand effects of land management processes on terrestrial carbon storage and the role of methanogenesis in carbon storage. A data base of land use and land management is critical

(Director's note: this need echoes recommendations of the biogeochemical cycling group and is addressed below).

Major research gaps identified under water quality and availability include the need: (1) to adapt models of reservoir water quality to assess climate change impacts; (2) to develop groundwater models that are responsive to climate change conditions; and (3) to incorporate wetland driving variables as examples of small-area, high-influence ecosystems.

Major research gaps identified under biodiversity include the need: (1) to develop and refine "metapopulation" models; (2) to conduct studies of genetic diversity; (3) to examine effects of climate change on landscape structure and habitat as a basis for studying the overall response of biodiversity to climate change. Again, data bases for examining the impacts of climate change on biodiversity are not available, except in special cases (e.g., the Breeding Bird Survey).

Scaling Group. The scaling group identified a small set of research needs that warrant future attention of the GPRC, especially as the first round of GPRC research projects nears completion and results must be integrated/synthesized, including: (1) the tracking of residual values from process and modeling studies such as, for example, following the route taken by water left by crop growth models in undefined soil layers toward stream runoff or the coupling of evapotranspiration from plants with regional climate models; and (2) properly weighting the role of strong but geographically small signals (for example, whether explicitly to represent a wetland in a landscape model or to average the wetland into the landscape).

Actions Prompted by the Workshop

Several recommendations made by the groups were studied and prioritized for potential action by the GPRC Director in concert with the GPRC Scientific Advisory Committee. As a result of high priority recommendations, efforts have begun:

* To coordinate the assemblage of climate change scenarios produced with three different techniques (stochastic downscaling of Bogardi and colleagues, nested regional modeling of Mearns and colleagues, and calendar shifting of Palecki and colleagues) into a package to be made available to other NIGEC investigators in need of climate change driving variables. Dr. Mearns is leading the development of the package.

* To insert a land use/land cover change component to the impacts thrust of the GPRC in order to develop a dynamic land use/cover classification that is responsive to climate and other environmental and human forcing.

* To fund with FY95 money new studies of: (a) the effects of elevated CO_2 and climate change on above and below ground partitioning of biomass for native prairie species (Charles Rice, Kansas State University); (b) the effects of climate change on pest (grasshopper) physiology and population characteristics (Anthony Joern, University of Nebraska-Lincoln); and (c) the effects of climate change on the surface hydrology of the Missouri River system with explicit linkage to water resources.

A recent survey of GPRC PIs (with limited response) found some tangible instances where the workshop discussions either prompted the development of research teams to assemble appropriate proposals or the exchanges of data and information between funded research teams, including: (1) the development of the Missouri River project mentioned above linking surface hydrology with water resources and economics; (2) the transmission of root biomass data from the soil study of Blair and colleagues to Tieszen and colleagues for use in modeling soil organic matter changes under climate change; (3) coordination of graduate student training between groups (for example, Tieszen's referral of students to Rundquist).

Research Integration with ARM-CART: Eco-ARM

Under the auspices of the GPRC and Battelle/Pacific Northwest Laboratories (PNL), discussions began in FY93 to plan the development of an ecological research effort to complement the research activities and utilize the facilities of the DOE's Atmospheric Radiation Measurement-Central Area Research Testbed (ARM-CART) program in eastern Oklahoma-Kansas. The GPRC and PNL co-hosted a workshop in March, 1994 in Lincoln to bring agency representatives and researchers together to assess the desirability and feasibility of such an effort. The workshop produced a broad outline for a proposed research program known informally as "Eco-ARM." Possible research topics of Eco-ARM include: (1) dynamics and net ecosystem exchange of greenhouse gases in grasslands and agro-ecosystem, (2) linkages of soil moisture, temperature and greenhouse gas fluxes in grasslands and agro-ecosystems, (3) impacts of management practices on greenhouse gas fluxes, (4) response of plants to CO_2 - enrichment under the wide range of soil and climatic conditions within the ARM-domain, (5) influence of vegetative cover on watershed dynamics and water quality, (6) effects of biomass plantations on surface radiation balances, energy balances and carbon budget, and (7) comparative studies of biomass productive capacity and management methods under varied climatic and soil conditions of the ARM-CART site.

GPRC and Battelle follow-on efforts to the workshop over the remainder of FY94 INCLUDED: (1) the development of a prospectus of research on climate and land use change interactions with surface fluxes of carbon dioxide and water vapor across the ARM-CART ecotones; (2) a site visit by a team of researchers to the ARM-CART region to assess potential flux measurement sites and to outline a research strategy; (3) the development of multiple proposals for funding of the research components of such a strategy; and (4) continued negotiation with ARM program managers to secure support for instrumentation.

Significant progress has been made toward development of a research project on climate and land use change interactions with trace gas fluxes. Research led by Dr. Easterling to examine land use change-ecosystem interactions in the ARM-CART region will be funded by the National Science Foundation. Dr. Shashi Verma of the University of Nebraska-Lincoln, a GPRC investigator, has developed a proposal to measure and model carbon dioxide and water vapor fluxes and their biophysical controls on two different land covers (tall grass prairie and wheat) in the ARM-CART region. Elements of Dr. Verma's proposal will be submitted to the GPRC.

Also, the GPRC is actively soliciting proposals that focus on some aspect of the GPRC's research thrusts within the ARM-CART region.

FUTURE DIRECTIONS FOR THE GPRC

The GPRC will continue efforts to develop a set of interconnected studies leading to an accumulative assessment of the impacts of climate change on the Great Plains and the quantification of the region's net carbon exchanges to and from the atmosphere. In addition to new efforts discussed in the previous section, the GPRC will stress the development of team research that mechanistically links process-level information on impacts and net carbon exchange with ecosystem-level models. Strong linkage will also be sought between ecosystem models and socioeconomic analysis.

Work that mutually complements the research goals of the GPRC and the ARM-CART program in Kansas-Oklahoma, especially that which focuses geographically on the ARM-CART region and utilizes data and/or instrumentation suites there, will receive high priority for funding. Research relevant to the GPRC that focuses on other dedicated research sites in the Great Plains (LTER sites, protected natural areas, agricultural experiment station testplots) is also encouraged.

BIOGEOCHEMICAL CYCLING GROUP REPORT

Jay Ham, Rapporteur
Great Plains NIGEC Workshop, Lincoln, Nebraska
September 29-30, 1994

Members and Participants

Shashi Verma (chair), Jay Ham (rapporteur), John Blair, Vern Cole, Joon Kim, Don Rundquist, Larry Tieszen, Frank Ullman, Dave Gosselin, Kyle Hoagland

Introduction

The biogeochemical cycling group was primarily composed of scientists that were conducting field experiments to examine how key biogeochemical processes may interact with climate change in the Great Plains region. The goal of most of the group was to obtain a better understanding of the biophysical processes that influence the biology, hydrology, and trace gas dynamics of principal ecosystems and land use types. The objectives of the breakout group session were: (1) identify strengths and gaps within the regional program; (2) examine possible interactions within the biogeochemical cycling group; (3) develop a flowchart of feedback and interactions between the different research groups; and (4) make a list of questions and research needs to present to the other breakout groups.

Strengths and Gaps Within the NIGEC Program

Strengths

✓ Diverse Scientific Expertise. The regional program employs scientists with wide range of scientific skills and backgrounds. It is rare to see an integrated project that has global climate modelers interacting with process-level scientists working with microscopic/local mechanisms. This is exciting because an understanding of climate-terrain feedback can only be achieved when the dynamics of the entire terrestrial-atmosphere continuum are considered.

✓ Research at Multiple Scales. The NIGEC program is funding projects that operate at multiple spatial and temporal scales. This effort should allow experimental findings at micro and local scales to be extrapolated to regional levels. Additionally, regional climate change scenarios from large scale GCM models will allow local scale scientists to formulate better hypotheses and conduct more realistic field experiments.

✓ Valued Added Projects. Much of the research conducted as part of NIGEC will benefit other research efforts not directly linked to NIGEC (e.g., NSF LTER sites).

✓ Diverse Funding Sources. Many of the NIGEC investigators appear to have obtained funding from other sources to supplement their regional projects. Thus, the NIGEC program acts as a catalyst to stimulate extramural funding.

Gaps in the Regional Program

✓ Lack of Balance Between Measurement and Modeling. The group was concerned that the regional program contained too much modeling and not enough measurements. While the biogeochemical group clearly saw the value of modeling, they did believe that modeling must done with at least "one foot in the field". That is, measurements must be used to develop better process-level submodels and to verify the performance of regional models by comparing measured and modeled results.

- ✓ Land-use Classification. Many researchers believed that land use and changes in land use need to be quantified for the Great Plains. Scaling procedures can not be employed without this information.

- ✓ Standardization of Field-Study Data Collection. Experimenters working on different ecosystems and land use types should work with modelers to develop a list of variables that are measured at all locations.

- ✓ Control and Patterns of Large Scale (synoptic) Weather Patterns / Air Movement.

- ✓ Improved Linkage Between Hydrologic Models and Ecosystem models.

- ✓ Seek Linkage Between NIGEC and Other Great Plains Projects (e.g., LTER sites)

Possible Interactions Within the Biogeochemical Processes Group

- ✓ Application of stable isotope analysis to grasslands and wetlands (Tieszen, Verma, Ham)

- ✓ Application of soil biogeochemical models (i.e, Century) to soil core experiment and wetlands study (Blair, Rundquist, Tieszen, Verma, Neilson and Ojima)

- ✓ Aerial extent of emergent vegetation by satellite remote sensing (Rundquist, Verma).

- ✓ Comparison of flux monitoring techniques (Ham, Verma).

- ✓ Interaction between soil microbial processes and the surface energy balance (Ham, Blair, Rice)

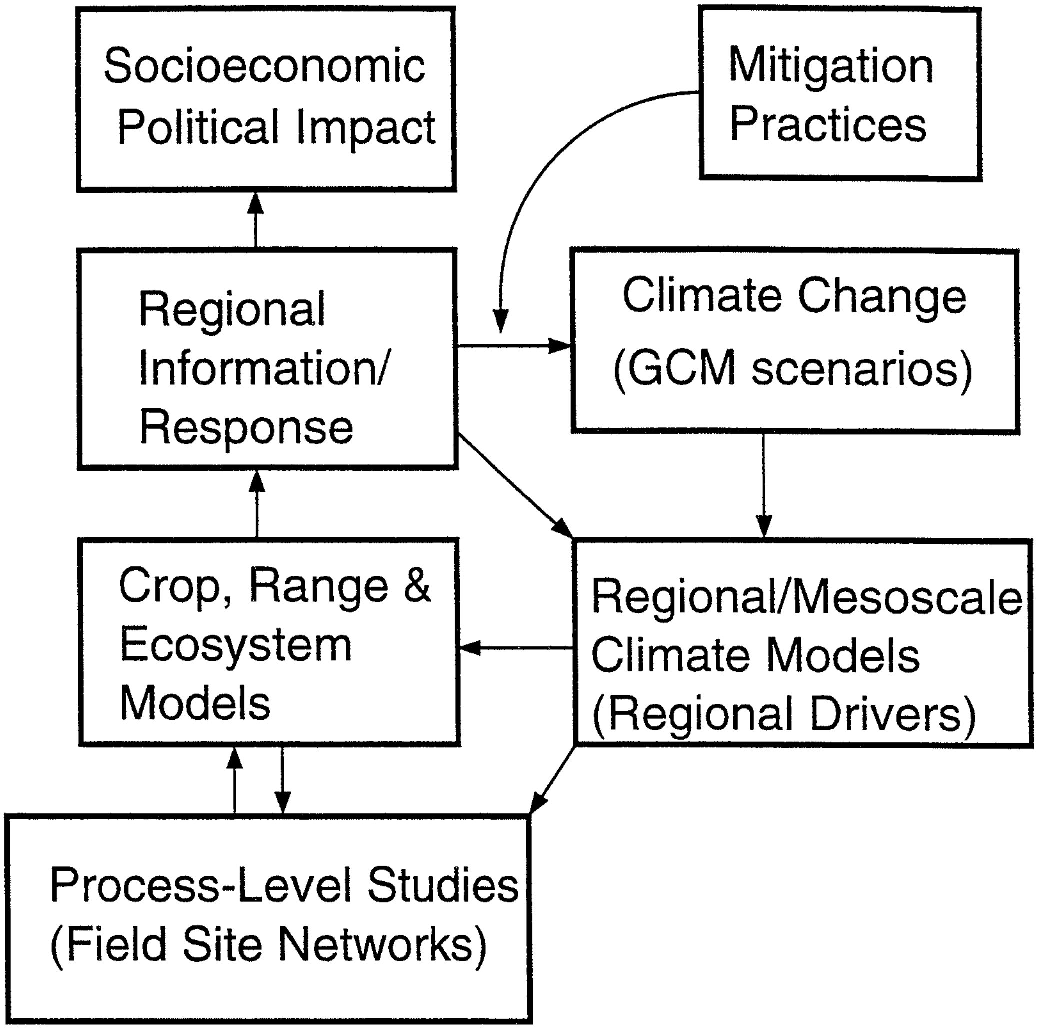
Diagram of Interaction Within the Regional NIGEC Program

The group developed a flowchart depicting the exchange of information between the different research groups within NIGEC (see attached figure). The rationale for the chart was as follows: (1) the process-level studies will provide basic information/submodels to the crop/range/ecosystem models; (2) the ecosystem models will couple the process-level information with regional climate drivers to simulate the effect of climate on biophysical-mediated productivity and trace gas dynamics (any many other parameters); (3) the results from the ecosystem models will be used to determine the impact of climate on the regional land-use changes, C Budget, hydrology, etc.; (4) regional responses will be used to estimate the socioeconomic impact of climate; (5) Climate change will be influenced by the dynamics of the region as well as influence regional climate (thus completing the loop); and (5) mitigation practices can be explored to reduce the impact of the region on climate change.

Questions for the Other Breakout Groups

The biogeochemical cycling group did not formulate a set of specific questions for the other research groups. However, the group did want to know how the information that they were collecting was going to be incorporated into regional scale research. It was clear that the process level researchers will need to find collaborators within the regional modeling groups to scale their findings to regional levels.

Proposed Interactive Flowchart
Great Plains Regional Research Program
NIGEC Regional Center, Lincoln, NE



Proposed by Biogeochemical Processes Group
NIGEC Regional Meeting, Lincoln, NE 9/29/94

CLIMATE CHANGE SCENARIOS GROUP REPORT
Michael A. Palecki, Rapporteur
Great Plains NIGEC Workshop, September 29-30, 1994

September 29

Participants: Linda Mearns (Chair), Michael Palecki (Rapporteur), Istvan Bogardi, Ken Dewey, Lucien Duckstein, Istvan Matyasovszky, Clinton Rowe, Dan Leathers, Gene Tackle, Reka Molnar, Wolfgang Diemhofer, Roland Reiter

Three main topics occupied the Climate Change Scenarios group:

1) What is the best way to facilitate collaboration among the three major research groups that are developing climate change scenarios for the Great Plains (First Order Collaboration)?

2) Are there outstanding issues and/or research gaps in the provision of climate change scenarios that should be addressed (General Issues)?

3) How will the information contained in group scenarios be made available to other Great Plains Center research groups (Second Order Collaboration)?

Topic 1: First Order Collaboration

The major collaborative effort of the group will be an intercomparison of climate change scenarios for the Great Plains of the United States. Each scenario generation method will be driven by the same GCM run. In order to facilitate this activity, a detailed discussion of each of the three scenario-generation methods represented in the group was required. This dialogue was structured so as to allow for an exploration of the techniques being utilized, the strengths and weaknesses of each method, and the climate variables output for each scenario.

The group led by Bogardi is using a down scaling technique (DS) that statistically relates fields of large scale atmospheric circulation to surface climate states. First, observed 500 mb atmospheric circulation patterns are reduced to principal components and then clustered into individual classes. This is done separately for each of the four seasons. The temporal properties of each circulation type are identified, focusing on their persistence and transitional probabilities. The probabilities of any given day having a certain 500-mb circulation pattern can then be modelled as a Markov process. In addition, probability distributions for climate variables (e.g., precipitation occurrence, precipitation amount, temperature, etc.) exist for each type of circulation, so one can synthesize time series of surface climate variables. To create a scenario, the 500 mb geopotential height and circulation pattern probability changes from a control GCM run to a doubled-CO_2 GCM run are added to the observed heights and circulation probabilities, allowing the statistical generation of scenario time series of any length.

A new and seemingly simple approach to climate scenario generation called calendar shifting (CS) is offered by the group led by Palecki. This approach uses large scale regional temperature differences between doubled-CO_2 and control GCM runs; in this case, the change in the annual cycle in the Great Plains is calculated from model output. These monthly temperature differences are then referenced to the observed annual cycle, and the time period of the year with the equivalent temperature is determined. Observations from the newly selected calendar dates are then used to represent the model scenario month in question. In mid-summer, observations from a limited subset of war-m years are used to provide scenario information beyond the range of the normal annual cycle at a location. The final product is a set of re-ordered but genuine climate observations that are dynamically consistent.

A nested modelling (NM) approach to future climate scenario production is being employed by the group led by Mearns. A large scale global domain model run of a doubled-CO_2 climate is used to provide the boundary conditions for a mesoscale climate model. The mesoscale model is then operated over the same time interval as the driving global GCM model nm. The enhanced resolution of the mesoscale climate model allows for the production of a high resolution climate change scenario based on first physical principles. Observed daily variances are then incorporated with the modelled climate changes to complete the scenario.

All of these approaches to climate change scenario production have strengths and weaknesses. The DS method relies on one of the most robust fields modelled by GCMS: the large scale mid-tropospheric geopotential height patterns. The stochastic nature of the resulting scenario product allows for the assessment of changes in the probabilities of extreme climate anomalies with long recurrence intervals. In addition, observed spatial relationships between locations are maintained within the generated scenario. Finally, the DS method has wide-ranging applicability, as the same approach can be applied to many different variables.

Some of the same features of the DS method that are important advantages in scenario production can also be considered to be disadvantages. The assumption of a fixed relationship between circulation patterns and surface climate variables through a period of climate change can never be verified. Further, the control run GCM circulation classes are somewhat different from those observed. Even larger problems exist with the method during summer months, when midtropospheric flow and precipitation are often decoupled.

Climate modelling approaches have one compelling advantage above all semi-empirical methods: the resulting scenario is based on the available theoretical knowledge about the response of the climate system to the physical forcing of increased atmospheric $C0_2$ levels. Feedbacks between atmospheric and surface processes during climate change are fully represented. The NM strategy has the additional benefits of high spatial resolution, complete physical consistency between variable fields over space and time, availability of all climate variables of interest, and total spatial and temporal coverage for a region.

Unfortunately, the NM approach is computer intensive, and, therefore, resource restrictions limit the length of model runs. More importantly, many processes are not well described by physical laws at the aggregation scale of model grid cells, forcing a reliance on parameterizations that may not be valid under perturbed forcings. In addition, errors in the global-scale GCM climate can be propagated into the nested model through boundary layer conditions.

The CS technique has the advantage of simplicity. By relying on the direct time translation of daily observations, all scenario variables are dynamically consistent with each other, and natural modes of variability are fully represented. The technique may be applied to many different surface variables simultaneously, once the shift calendar has been identified.

The major assumption made when operating the CS method is that a seasonal shift forcing is analogous to an increased $C0_2$ forcing. In addition, it is concluded that the relationships between all the different surface climate variables is maintained through a period of changing climate. Finally, the CS approach does not allow for possible changes in the association between mean climate variable states and their variances.

<u>Topic 2: General Issues</u>

After clarifying the methods of scenario production, including their advantages and disadvantaged, the group commenced a more philosophical discussion regarding the merits of scenarios for impact assessments. Is there a reason for using complicated methods to generate improved scenarios? Has the nature of scenarios changed in some fundamental manner? In response to these questions, a statement was made and agreed to that scenarios have become more complex, but that we are no closer to confirming their validity than we were in the past. The possibility of unexpected outcomes still remains large. It became clear that everyone is assuming that global warming will take place, whether this conclusion is based on physical principles or GCM runs. This may leave us in the dangerous state of not having tested our impacts models for the effects of an unanticipated outcome, such as a temporary cooling. Perhaps some more effort must be applied to understanding the uncertainties of any one climate change scenario being validated. It is recommended that all impacts modelers, even if they normally examine the response of their models to realistic climate change scenarios, should also run their impacts models through carefully controlled sensitivity analyses covering a wide range of possible outcomes.

Topic 3: Second Order Collaboration

The availability of variables from each scenario was discussed in the context of the needs of impact assessors. The DS method can produce probability changes for almost any surface climate variable with sufficient observations to establish a relationship with circulation. All desirable climate variables are available from the NM approach; selected variables must not exceed mass storage capacities, and must be requested before the model run. All climate variables that have sufficiently long time series to characterize a mean seasonal cycle, except those directly involving radiation, can be derived from the CS method once the time shift dates have been determined.

A brief set of variables - maximum temperature, minimum temperature, and precipitation - has been chosen for special consideration in scenario intercomparisons and for standard output products to be archived for second order collaborators. Variability statistics may also be included in this archives The spatial domain of the DS scenario will be limited to selected stations, while the NM and CS scenarios will cover the region of the Great Plains. Each scenario will be produced using the same doubled-CO_2 model run as its starting point in order to facilitate intercomparison. Assuming the global GCM model run is available by March 1995, the DS and CS groups will have their scenarios completed by late summer 1995, while the NM runs will not be completed until late 1995.

The conditions for use of the scenarios by the impacts community led to the discussion of an important philosophical problem: do we let impacts people do what they want, or do we try to limit their usage to appropriate applications? The decision was made to provide written guidance regarding the assumptions of each scenario producing method, their shortcomings, and suggested limitations regarding their appropriate use. In fact, the scenario producers will be available to act in an advisory capacity to other impact assessors, perhaps through the organization of a workshop for this purpose. One of the primary recommendations that should go forward to the impact assessors is to test their own models through sensitivity analyses and simulations of historically warm periods like the 1980s. Further discussions with a wider community of impact assessors is needed to examine our recommendations and comment on them.

September 30

Participants: Linda Mearns (Chair), Michael Palecki (Rapporteur), Istvan Bogardi, Ron Neilson, Kyle Hoagland, Jim Brandle, John Blair, Jay Ham, Bill Smith, Dave Gosselin, Tony Joern, and John Antle.

The main goal of this session was the exchange of information between climate change scenario producers and climate change impact assessors. The dialogue was organized around a sequential presentation of the data input needs of various impact assessment projects, followed by a brief discussion of the logistics of scenario availability.

Studies of large-scale changes in vegetation require monthly temperature, precipitation, humidity, and wind speed data. Even with the best resolution scenarios, additional software packages must still be used to interpolate data onto finer grids over complex terrain. One approach to the integration of scenario data is to take the observations of climate variables interpolated over study regions, and then multiply them by the ratio of doubled-CO_2 to control scenario output variables. Differencing (doubled-CO_2 minus control) is utilized in altering temperatures only.

Many climate change impact assessments must be performed on truly microscale levels of detail, especially when concerning agricultural applications. Pests such as grasshoppers are temperature dependent, as well as forage dependent. Susceptibility to pest outbreaks is often keyed to climate conditions over very small areas, such as sections of counties. When looking at agricultural conditions around shelter belts, the local climate changes are of paramount importance; small shifts in wind statistics can create differential impacts. The assumption must be made that the microclimatological spatial behavior during observed extreme warm events must be similar to those in a doubled-CO_2 future, as there is no way to independently determine these patterns. Studies of climate change impacts on small water bodies and wetlands also have similar scaling concerns, and demand climate change variables that are usually not available, such as sunshine and evaporation.

The major theme that emerged from this discussion was scale. Even with the advent of scenario production methods which output data at grid scales or station separation distances of 50 km, there is always going to be a need for further down scaling of the information to local and even microscales. This is an especially difficult problem when dealing with process-level models calibrated at individual sites. It was concluded that process model developers and impact assessors must be the ones to develop their own specific ways of using available scenario information at microscales.

A discussion of the type of climate variables that are included in scenarios, and the assumptions under which scenarios are developed, reviewed for the new participants much of the content of the previous session. The types of variables of interest to impacts assessors goes well beyond the typical temperature and precipitation variables, to include relative humidity, surface hydrology, wind speed and direction, net radiation, sunshine hours, and photosynthetically active radiation. In addition, some of these variables must be characterized at more frequent then daily time intervals. The DS scenario approach can provide time series of any of these variables, as long as a sufficient time series of observations exist to characterize the variables at a location. This is also true of the CS technique, although it is not recommended for use in determining radiation variables. Finally, the NM method, although capable of producing any variable field of interest, is in practice limited to a set of major fields due to mass storage requirements: maximum temperature, minimum temperature, relative humidity, incoming solar radiation, wind speed, and clouds. Any variables not saved during the model run are lost. All three methods will produce variance statistics for the selected scenario variables.

The three types of scenarios will be available for use by impact assessors during NIGEC Fiscal Year 1995. Results for the DS and CS methodologies will be available for several different GCM guidance runs, although only a subset of the Great Plains region will be available from the DS group. Documentation of techniques and assumptions will be archived along with the scenarios, and each group will provide guidance to these products. If sufficient interest arises, a workshop on the use of climate scenarios may be organized. Overall, the exchange of information and ideas proved to be quite useful for both the climate change scenario users and the impact assessors.

MANAGED AND UNMANAGED ECOSYSTEM EFFECTS GROUP REPORT

David S. Guertin, Rapporteur
Great Plains NIGEC Workshop, Lincoln, Nebraska
September 29-30, 1994

Participants

Ted Elliott (Chair), David Guertin (Rapporteur), Jim Brandle, Geoff Henebry, Kyle Hoagland, Tony Joern, Ron Neilson, Chuck Rice

INTRODUCTION

In the Great Plains, few ecosystems could accurately be called completely unmanaged, but some systems are managed more intensely than others. Wetlands, for example, are not entirely unmanaged, but are still less intensely managed than crop lands. Our discussion in this group therefore considered effects on ecosystems under varying intensities of management.

By using a common approach to various topics in this discussion, we may link disparate projects together through related processes, and identify topics and research areas that have received little attention to date. We derived a framework containing five components (Fig. 1). Relevant issues or impacts of climate change are areas of study with both scientific importance and policy relevance. For each issue we identified important research approaches, and processes, driving variables, and data bases that serve as inputs to these research approaches. These areas are discussed below and are summarized in Table 1. Within this framework, we identified important areas of overlap in research topics, as well as gaps in research that should be addressed.

ISSUES

We discuss four important impacts of climate change. This is not an exhaustive list, but rather the topics that received the most attention within the breakout group. The discussion below refers to the items listed in Table 1, especially those topics that were specifically identified as research gaps. Note that Table 1 does not specifically list climate, land use and management, and economics and policy as driving variables. These three variables are driving variables for all impacts of climate change, and therefore are not listed separately in the table; they also are important gaps in our current knowledge. While data are available for past and current climate, prediction of future climate is very uncertain. Effects of land use and management and economics and policy on each of the four impacts discussed are also largely unknown.

1. Productivity

Prediction of potential effects of climate change on productivity is an important research topic for a wide range of ecosystems, including intensively managed systems such as crop lands, where development of cropping systems in response to climate change is an important goal. Effects on productivity are also important to understand in less managed systems such as grasslands (importance of grazing patterns), aquatic systems (phytoplankton populations as essential components of food webs), and wetlands. In some parts of the Great Plains region, forested systems are present, and production models for Great Plains forests is an important gap in our knowledge. Most studies of productivity do not include the role of animals, and this also is a research gap.

Reservoirs and ground water are important inputs to productivity for which our current information is deficient. The roles of both plant growth and pests(including insect, plant, and microbial pests) in productivity are also important gaps in knowledge. Table 1 lists three data bases for studies of productivity, but overall there is substantial room for improvement in data bases both for developing and for testing models.

2. Carbon Storage

Models and mass balance equations are two types of approaches to carbon storage. Models are fairly well developed, with the exception of remote sensing models. The below-ground components of carbon storage, are however, very little known.

Three processes affecting carbon storage deserve more attention. The effects of management practices is little known, as are some aspects of herbivory. The role of methanogenesis has been gaining increasing attention. A data base of land use and management would be useful, but none is available currently. DEM data on elevation are available for large scales, but not small scales.

3. Water Quality and Availability

Water resources are critical for both intensively managed and less managed systems. Hydrologic models are well-developed, but models of reservoir water quality and ground water models are not. Most inputs to these models are fairly well-studied, with the notable exception of the role of wetlands as a driving variable in the models.

4. Biodiversity

Effects of climate change on biodiversity are best studied using a population-or community-level approach. Metapopulation models are particularly well-suited to heterogeneous landscapes; this approach is still not fully developed, but its use is growing. Definitions of biodiversity vary; species diversity may be a gauge of the health of ecological communities, or particular species may act as indicators of community response to climate change. Studies of genetic diversity have been underrepresented but have been getting increasing attention. The effect of climate change on habitat and landscape structure, and thus indirectly on biodiversity, is a significant research gap.

Dispersal, migration, bioenergetics, and habitat use are processes that affect population approaches to biodiversity. These are all species-dependent processes, and although they are known for a small number of species, they are unknown in many more. Data bases relevant to biodiversity are scarce. Some data bases, such as the Breeding Bird Survey, are available, but overall the availability of data is a large gap in knowledge.

CONCLUSIONS

Our discussion could not identify all research topics that are relevant to climate change and ecosystems; nevertheless, it did bring to light several important research gaps. In addition to those listed above, the development of a land-use model would be an important aide to research in the Great Plains. This corresponds with land-use being an essential driving variable for all research approaches in this region, and underscores the importance of human economic systems as influences on ecological systems. Consideration of spatial and temporal scaling is also essential in most research approaches.

Finally, we recommend three improvements to the logical structure of the Great Plains Regional research program. First, the importance of land use as a driving variable should be made more prominent. Second, there should be more explicit incorporation of scaling. Third, the program is more usefully viewed in two separate but related frameworks: 1) the organization of the Great Plains regional project, and the research programs contained within it; and 2)the organization of scientific concepts and knowledge (e.g. Fig. 1).

Table 1: Components of each of the four main issues discussed. Bold text denotes items that were identified as research gaps. Climate, land use/management, and economics/policy were identified as driving variables for all four issues, and are not included in the table.

	Issues			
Components	Productivity	Carbon Storage	Water Quality/Availability	Biodiversity
APPROACHES	• Production models: 1. crops 2. grassland 3. **forest** 4. aquatic/wetland • Experimental manipulation • Remote sensing • **Animals**	• Models: 1. plants 2. soils 3. **remote sensing** 4. ecosystem • Mass balance calculations 1. **Below-ground components**	• Hydrologic models • **Reservoir water quality models** • **Ground water models**	• Level of modeling: 1. population 2. **metapopulation** 3. community • Type of diversity 1. **genetic** 2. species 3. functional groups • **Habitat approach**
PROCESSES	• **Plant growth** • Nutrient cycling • Water balance • Water quality degradation • **Reservoirs** • **Ground water**	• Water balance • Decomposition • Production (net) • SOM formation/loss • **Management** • Fire • **Herbivory** • **Methanogenesis**	• Runoff • Infiltration • Percolation • Evapotranspiration • Productivity	• **Dispersal** • **Migration** • **Bioenergetics** • **Habitat use**

continued on next page

Table 1: continued from previous page

	Issues			
Components	Productivity	Carbon Storage	Water Quality/Availability	Biodiversity
DRIVING VARIABLES	• Nutrients • **Pests**	• Water table • Topography	• Runoff • Productivity • Vegetation • **Wetlands** • Consumption	• Biophysical constraints • **Habitat/landscape**
DATA BASES	• Agr. census data • SCS data • Remote sensing data • **overall**	• **Land use/mgmt.** • Soil (esp. C) • Productivity • **DEM (elevation)**	• State water plans • USGS hydrol. regions • snow pack	• Breeding bird survey • **overall**

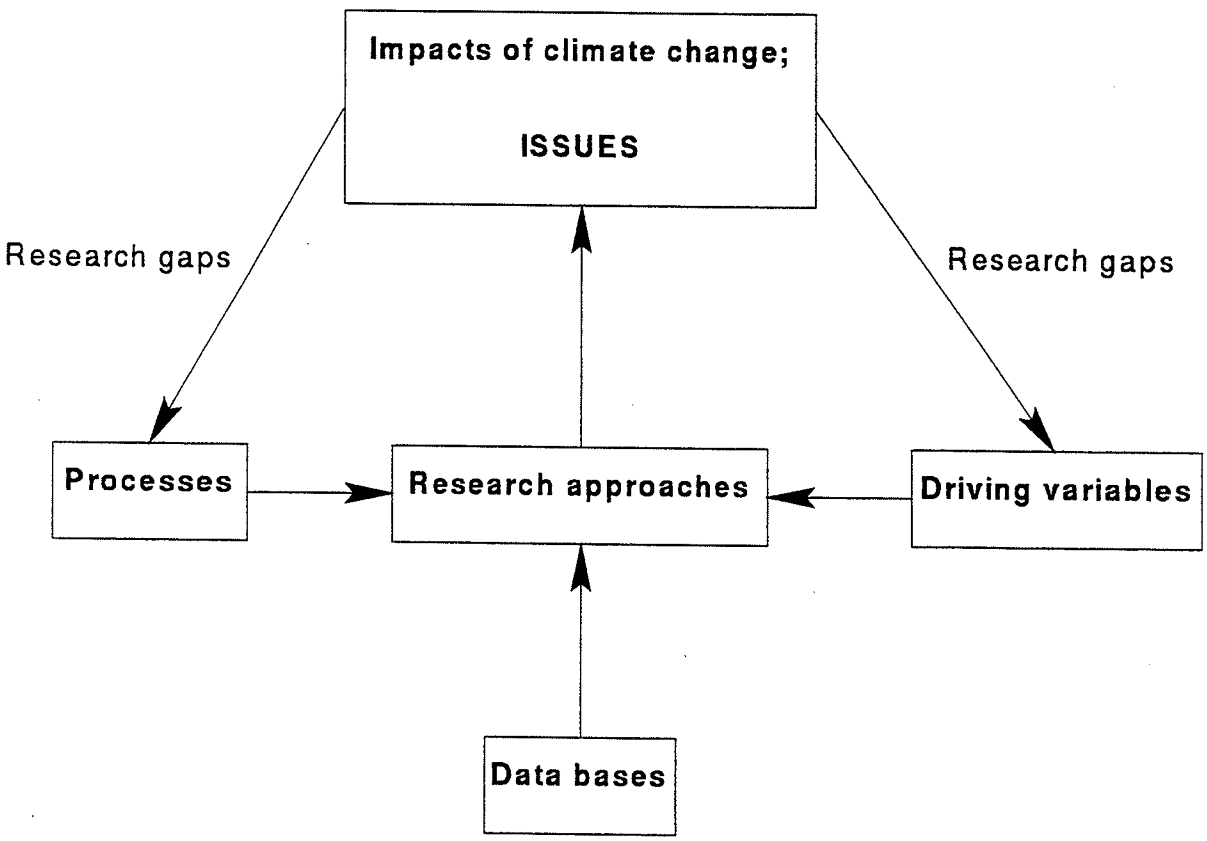


Figure 1: Framework used to view impacts of climate change on ecosystems. Appropriate research approaches are used to address each issue. Each approach has its own set of inputs, which take the form of processes, driving variables, and data bases.

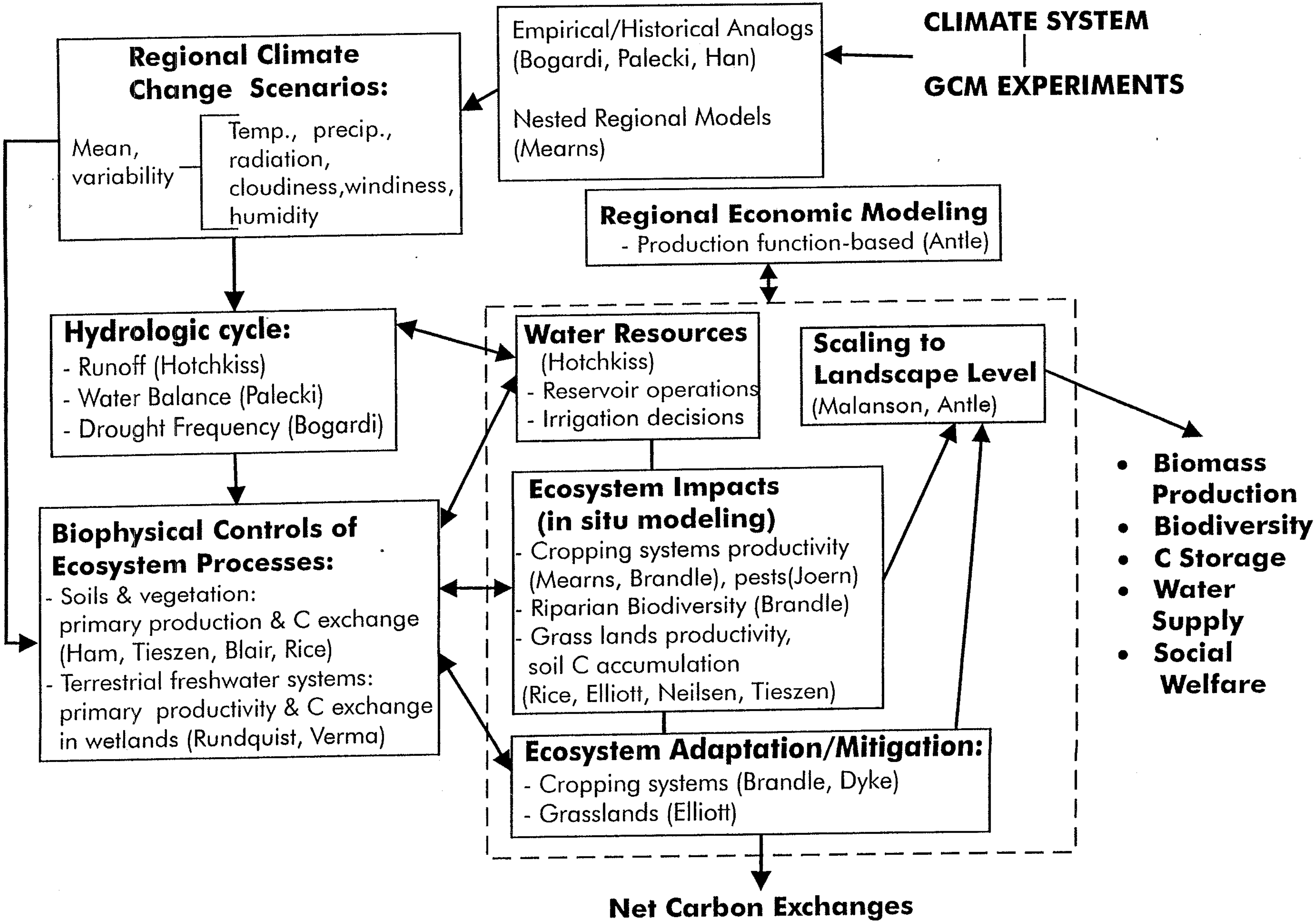
GREAT PLAINS REGIONAL CENTER FOR GLOBAL ENVIRONMENTAL CHANGE FUNDED PROPOSALS/PROJECTS 1994-95

PRINCIPAL INVESTIGATOR	PROJECT TITLE	AMOUNT	INSTITUTION(s)
VERMA, Shashi B. Valentine, David W.	An Integrated Investigation of Methane and Carbon Dioxide Fluxes in Mid-Latitude Prairie Wetlands: Micrometeorological Measurements, Process-Level Studies and Modeling	280,000	UNL CSU
MEARNS, L. Giorgi, F. Easterling, W. Weiss, A.	Development of a Nested Regional Model for the Conterminous United States and Formation of High Resolution Climate Change Scenarios with an Application to Crop Climate Models	118,000	NCAR UNL
TIESZEN, Larry L.	Assessment of Climate and Management Induced Directional Changes in Great Plains Vegetation with NDVI and Stable Carbon Isotopes	80,000	Augustana
BLAIR, John M. Todd, Timothy C. Rice, Charles W. Knapp, Alan K.	Effects of Altered Soil Moisture and Temperature on Soil Communities, Primary Producers, and Ecological Processes in Grassland Ecosystems	82,500	KSU
BRANDLE, James R. Easterling, William E. Takle, Eugene S.	Assessment of Climate Change on a Mixed Agricultural and Forest Landscape on the North American Great Plains	102,000	UNL ISU
ELLIOTT, Edward T. Cole, C. Vernon	Regional projections of C Dynamics with Global Change in the Central U.S.	100,000	CSU MSU
HOAGLAND, Kyle D. Ernst, Stephen G.	The Detection of Climate Change Using Living and Extinct Diatom Floras	55,000	UNL
BOGARDI, Istvan Matyasovszky, Istvan Duckstein, Lucien	Space-Time Local Hydrology Influenced by Changing Climatology: Disaggregation, Prediction and Comparison	120,000	UNL U of AZ
HAN, Qingyuan Welch, Ronald M.	The Effect of Ecosystems on Cloud Microphysics and Aerosol Distribution	63,000	SDSMT
DYKE, Paul T. Rosenberg, Norman J. Easterling, William E.	The Comparative Economics and Environmental Impact of Biomass for Energy Production under new Digester Technologies and Increased CO_2 Levels	70,000	TX A&M Battelle UNL
NEILSON, Ronald P. Ojima, Dennis Lenihan, James Daly, Christopher	Potential Global Warming Impacts on Vegetation Distribution,, Productivity, and Hydrology at Landscape to Regional Scales in the Great Plains Region	40,000	OSU CSU

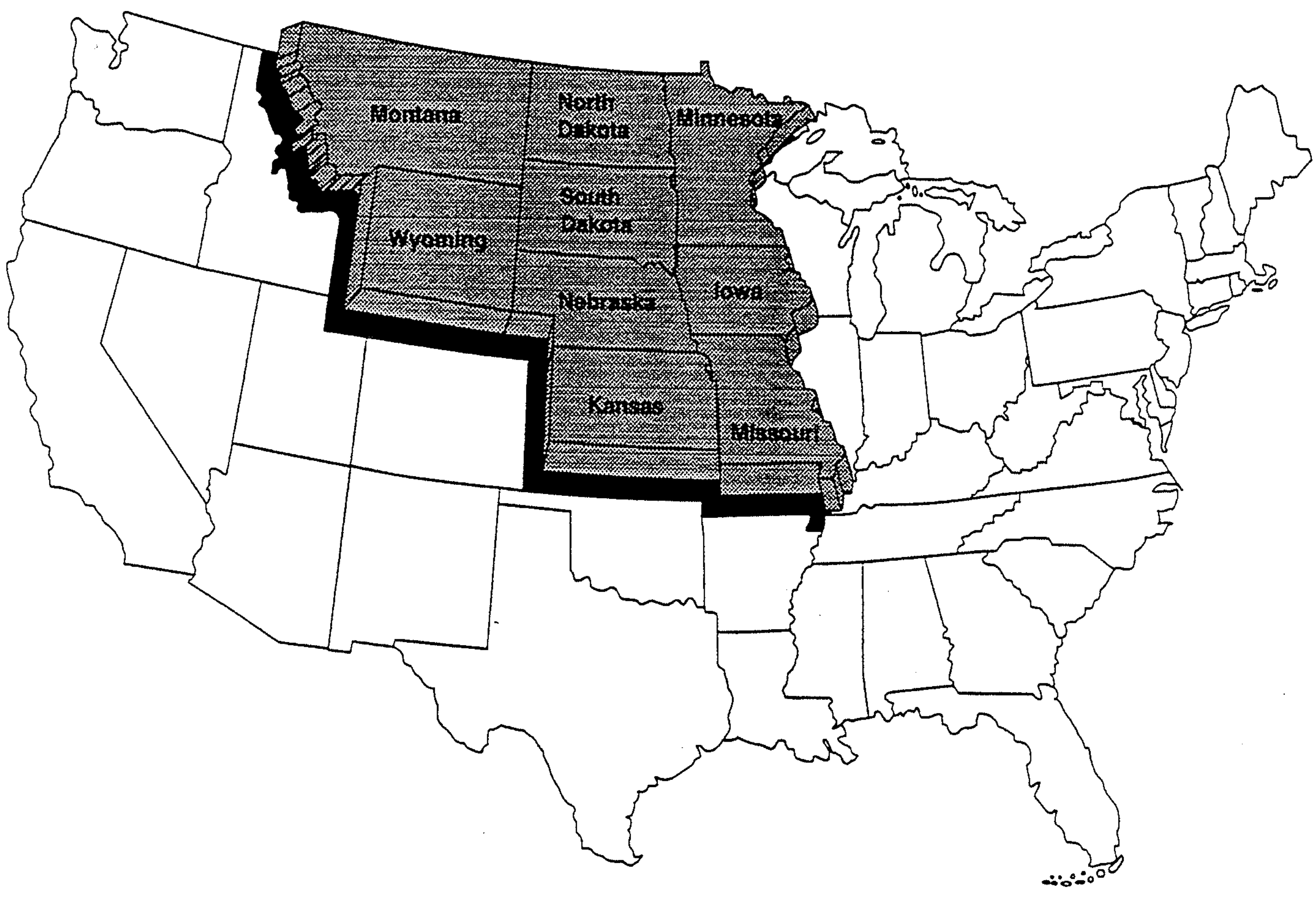
GREAT PLAINS REGIONAL CENTER FOR GLOBAL ENVIRONMENTAL CHANGE
FUNDED PROPOSALS/PROJECTS
1994-95

PRINCIPAL INVESTIGATOR	PROJECT TITLE	AMOUNT	INSTITUTION(s)
RUNDQUIST, Donald C. Gosselin, David C.	Natural Responses of Shallow Lakes and Wetlands for Detecting Climatic/Environmental Change	75,000	UNL
CHEN, Tsing-Chang Tribbia, Joseph J.	Observational and Numerical Study for Interannual and Interdecadal Variabilities of the Atmospheric Circulation	35,000	ISU NCAR
PALECKI, Michael A. Dewey, Kenneth Leathers, Daniel J. Robinson, David A.	The Detection of Climate Change Using Long Term Daily Climate Records Over Grassland Regions of the Northern Hemisphere	86,000	UNL U of DE Rutgers
GOSNOLD, William D. Todhunter, Paul	Climate Change in the Midcontinent of North America	40,000	U of ND
LILLESAND, Thomas M. Magnuson, John J.	Satellite Observation of Lake Ice as a Robust Indicator of Regional Climate Change	40,000	UW-M
HAM, Jay M.	Carbon, Water, and Energy Fluxes From a Tallgrass Prairie: A Long-term Investigation of Biological, Environmental, and Land Use Factors	30,000	KSU
MALANSON, George P.	Local and Regional Scaling With a Spatially Explicit Ecological Model	20,000	U of IA

Great Plains Regional Center Integrated Research Program



Great Plains Regional Center for Global Environmental Change



Effects of Altered Soil Moisture and Temperature on Soil Communities, Primary Producers and Ecological Processes in Grassland Ecosystems

John M. Blair, Alan K. Knapp, Timothy C. Todd and Charles W. Rice
Kansas State University

Objectives: We are investigating the potential consequences of climate change for grassland biological systems, focusing on functional effects at the individual, community and ecosystem levels. For the tallgrass prairie ecosystems at the eastern edge of the Central Plains region, patterns and amounts of precipitation, along with fire frequency and grazing, are key factors controlling ecosystem structure and function. The importance of climate, particularly precipitation, as a forcing function makes these ecosystems especially vulnerable to the changes in precipitation and temperature predicted by current global climate change models, although not enough is known to predict the magnitude of these changes or how they will affect ecosystem function over longer time scales. Our specific objectives are (1) to determine the responses of prairie grasses, soil organisms and key soil and plant processes to different soil moisture and temperature regimes and (2) to identify the potential consequences of these responses for ecosystem function in light of the predictions of global climate change models.

Products: Our research will provide new insights into the effects of altered soil moisture regimes on ecological processes in grasslands. This information is important for correct interpretation of the consequences of predicted shifts in the regional climate. Results of this research will be directly relevant to the Department of Energy's Global Change Research Program priority question regarding the response of terrestrial organisms and ecosystems to potential changes in climatic conditions (precipitation and temperature), the regulation and controls of these responses, and how these responses are integrated across organizational levels to produce adjustments in terrestrial ecosystems to climate change. Specific question we address are:

1. How will changing soil moisture levels and temperatures, a predicted consequence of global climate change models, affect plant productivity, soil communities and soil processes in tallgrass prairie ecosystems of the Central Plains region?

2. What are the likely consequences of changes in primary productivity, soil communities and soil processes for grassland ecosystem function (i.e., organic matter storage and turnover, nutrient retention and availability)?

Approach: We use naturally occurring gradients of soil moisture and/or temperature, at two very different scales, as experimental "treatments" to address the controls which moisture and temperature impose on ecological processes in grasslands. At a regional scale we have selected two sites (a mesic tallgrass prairie and a more arid mixed-grass prairie) with different climatic influences due to an east-west precipitation gradient. The more mesic tallgrass site is located at Konza Prairie Research Natural Area (KPRNA - 39°05N, 96°35W), and the more xeric mixed-grass site is at the Fort Hayes Agricultural Experiment Station (FHAES - 38°75N, 99°20W). A major component of our research involves reciprocal transplants of large intact soil cores and associated plants between these sites to address the effects of altered soil moisture availability and temperature on selected response variables. Seventy intact soil cores (25 cm diameter x 70 cm deep, encased in open-ended PVC cylinders) were extracted from both the KPRNA and FHAES sites using hydraulic soil coring equipment. At both sites cores were taken from areas dominated by *Andropogon gerardii* (big bluestem) to minimize variability among cores. Half the cores were placed back into holes at the site from which they were taken, and half were transplanted into holes at the other site, so that the soil surface of in situ cores was flush with the surrounding soil. The end result was a grid of 35 paired "tallgrass cores" and "mixed-grass cores" arranged in a randomized block design at each of the two sites. Data from "native" (non-transplanted) cores at each site allows us to compare soil communities, properties and processes in grassland ecosystems developed under different climatic regimes, while data from transplanted cores provides insights into how plants and soil communities, properties and processes respond to altered soil moisture and temperature. The use of "non-transplanted" cores also controls for the effects of the coring operation and encasement of the cores in PVC for the duration of the experiment. A representative subset of cores (n=5 of each core type at each site) has been instrumented to allow continuous remote monitoring of soil moisture, using Time Domain Reflectometry (TDR), and soil temperature. Sufficient cores were transplanted to allow for (1) intensive destructive sampling during the three-year funding period and (2) less intensive monitoring of longer-term (i.e., ten years) changes. A set of 10 cores from each site is destructively sampled twice a year (spring and autumn), and analyzed for total above- and below-ground plant biomass C and N, soil invertebrate numbers and composition, microbial biomass and activity, total soil N and C, and available soil N.

At a more local scale (KPRNA only) we are utilizing field sites with different average soil moisture availability, resulting naturally from topographic position, to examine the long-term responses of tallgrass ecosystems to different soil moisture and temperature conditions. We are using difference in water availability between upland and lowland sites to address the effects of chronic water stress on plant reproductive effort, biomass and NPP. In addition to these naturally occurring moisture gradients, we have expanded our local studies to include sampling along a topographic sequence to which supplemental irrigation water is added to reduce growing season water deficits. Both the regional reciprocal transplant experiment and the control and irrigated transects studies are relevant to understanding the consequences of climate change in the Central Plains region.

Results-to-Date: Research in the second year is progressing on schedule. Establishment of sites and placement of intact soil cores for the reciprocal core transplant experiment was completed in 1993, and sets of cores for periodic sampling and analyses were collected in May 1994, November 1994, and May 1995. These cores were processed and sampled for a suite a variables including: above- and below-ground biomass, plant nutrient content, extractable soil N, potentially mineralizable soil C and N pools, soil microbial biomass C and N, and soil invertebrate abundance and community structure. Many of these analyses are ongoing, but results to date have been useful for characterizing existing differences in plant and soil properties at our two field sites, and have already suggested some responses to changes in climate associated with the transplanted cores. For example, there were initial differences in both total below-ground biomass and depth distributions of grass roots at the Konza and Hays sites (Fig.1). The chronically drier conditions at Hays were associated with both lower total rhizome and root biomass, and differences in the depth distribution of root biomass, compared to Konza cores. We also found some marked differences in the potentially mineralizable C and N pools in soils from the Konza and Hays sites (Fig.2). Soils from Hays exhibited faster rates of soil C and N mineralization, relative to soils from the Konza site, when incubated under standard laboratory conditions, suggesting greater accumulations of mineralizable C and N in the more xeric site. One of the most interesting findings to date has been an apparent rapid decline in potentially mineralizable soil N in the transplanted Hays cores. Upper horizon (0-5 cm) soil collected in May of 1994 from FHAES cores which were relocated to the Konza site exhibited a much lower mineralization potential than soil from FHAES cores which remained at the Hays site (Fig.2A). A similar pattern was observed for potentially mineralizable C (Fig.2B). Preliminary results from incubation of cores collected in November of 1994 indicate the same directional changes in mineralizable C and N of transplanted cores. These incubations, when completed, will allow to calculate the initial size of the potentially mineralizable soil N and C pools (N_0 and C_0), as well as determine the response of these pools to changes in climate over time. We also have been able to document differences in the abundance and distribution of soil nematode at the Konza and Hays sites (Fig.3). Although we have not detected significant changes in total nematode abundance with the core transplants, we have found some shifts in the relative abundance of certain species. For example, a *Helicotylenchus* sp. which had a low abundance at Hays has been become a dominant species in Hays cores transplanted to Konza. This is a different species than is normally found in Konza. Analysis of soil microarthropods samples are ongoing.

Measurements of plant ecophysiological responses also were initiated at both sites in spring of 1994, and being continued in 1995. Physiological responses of *A. gerardii* native to each site are being compared with those of *A. gerardii* transplanted from the reciprocal site. Measurements included midday leaf xylem pressure potentials, and leaf-level net photosynthesis, measured with a LICOR portable gas analyzer. Results to date are presented in Fig.4. Midday water potentials indicated greater early and late season water stress at the Ft. Hays site, relative to cores at the Konza site. The effects of these periods of water stress on leaf level photosynthetic rates are apparent. These ecophysiological responses were translated into reduced aboveground productivity at the Hays site. Additional non-destructive indices of plant density and phenology also are being done to document differences in stand characteristics and plant phenology at the two sites.

In 1994 we expanded our measurements of plant productivity and soil N availability across topographic gradients at the KPRNA field site to include irrigated and non-irrigated transects. These measurements are being continued in 1994, with the addition of measurements of soil CO_2 flux. A related project in 1994 examined topographic patterns of soil N availability and above ground net primary productivity (ANPP). Results of that study demonstrated greater ANPP at wetter lowland sites, with the differences between upland and lowland sites being enhanced by burning. Surprisingly, topographic patterns of soil net N mineralization were the opposite of patterns of ANPP, and net N mineralization was greater at the drier, upland sites. The effects of soil moisture deficits on these patterns will be addressed as data from the irrigation transects become available.

Manuscripts in preparation and submitted:

O'Lear, H.A., T.R. Seastedt, J.M. Briggs, J.M. Blair and R.A. Ramundo. Fire and topographic effects on decomposition rates and nitrogen dynamics of buried wood in tallgrass prairie. Submitted to *Soil Biology & Biochemistry*.

Turner, C.L., J.M. Blair, R.J. Schartz and J.C. Neel. Soil N availability and plant response in tallgrass prairie: Effects of fire, topography and supplemental N. Submitted to *Ecology*.

Presentations:

Blair, J.M. 1994. Decomposition of above- and below-ground grass litter in tallgrass prairie ecosystems. 14th North American Prairie Conference, Manhattan, Kansas, July 1994.

O'Lear, H.A., T.R. Seastedt, J.M. Briggs, J.M. Blair and R.A. Ramundo. 1994. Decomposition of wood in soils of burned and unburned tallgrass prairie. 14th North American Prairie Conference, Manhattan, Kansas, July, 1994.

Blair, J. M., H. Su, J. C. Shaw and A. K. Knapp. 1994. Effects of topography and fire on soil processes and plant productivity in tallgrass prairie. Ecological Society of America meeting, Knoxville, TN, August 1994.

Knapp, A.K., J.M. Briggs and J.M. Blair. 1995. Long term ecological research at the Konza Prairie Research Natural Area: Lessons in sustainability from a native Great Plains ecosystem. Planning for a Sustainable Future: Great Plains Symposium, Lincoln, NE, May, 1995.

Student Participation (FY 94 only):

In FY 1994 two graduate students and a total of nine undergraduate student research assistants were involved in research and training activities supported by this project.

Name	University	Degree Sought	% Time on Project	NIGEC Funds Received
Sherry Ahlgrim	Kansas State U.	B.S.	10%	$ 954
Sherry Antholtz	Kansas State U.	B.S.	<5%	$ 206
Deane Coulson	Kansas State U.	B.S.	50%	$ 2,150
Mitchell Emig	Kansas State U.	B.S.	25%	$ 1,162
Brian Haverkamp	Kansas State U.	B.S.	25%	$ 1,455
Cathy Hitchcock	Ft. Hays State U.	B.S.	25%	$ 3,953
Angela Lambley	Kansas State U.	B.S.	25%	$ 578
Krista Mobley	Kansas State U.	B.S.	50%	$ 3,010
Jeffrey Neel	Kansas State U.	B.S.	50%	$ 5,428
Heather O'Lear	Kansas State U.	M.S.	100%	$ 8,216
Antonio Omay	Kansas State U.	Ph.D.	75%	$ 7,564
				$34,676

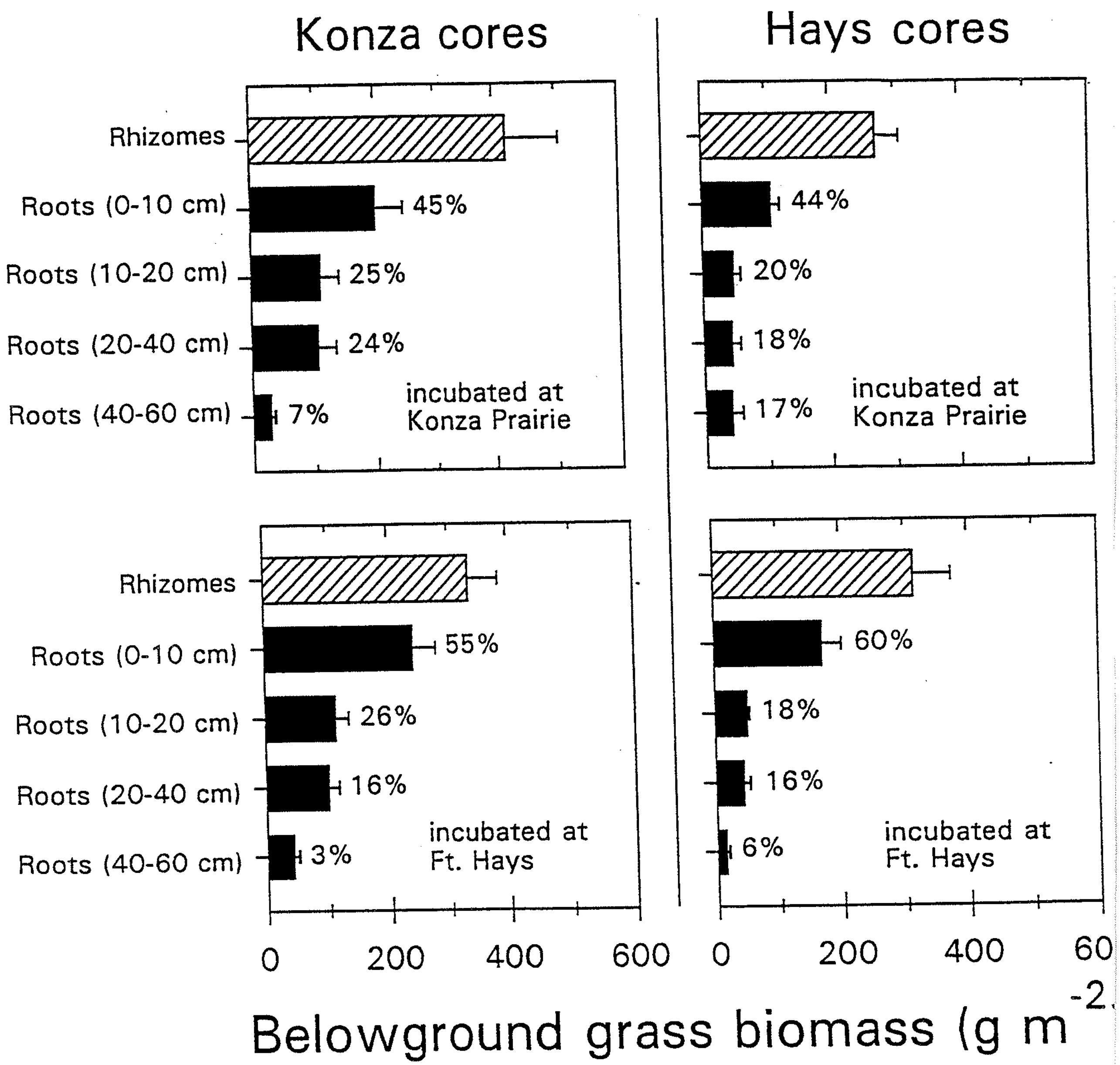


Fig. 1. Biomass and depth distribution of grass rhizome and root biomass in cores collected in November 1994, one year after the start of the reciprocal transplant experiment (see text for explanation). Percentages next to horizontal bars represent the percentage of total live grass root mass found in each of the four depth increments sampled.

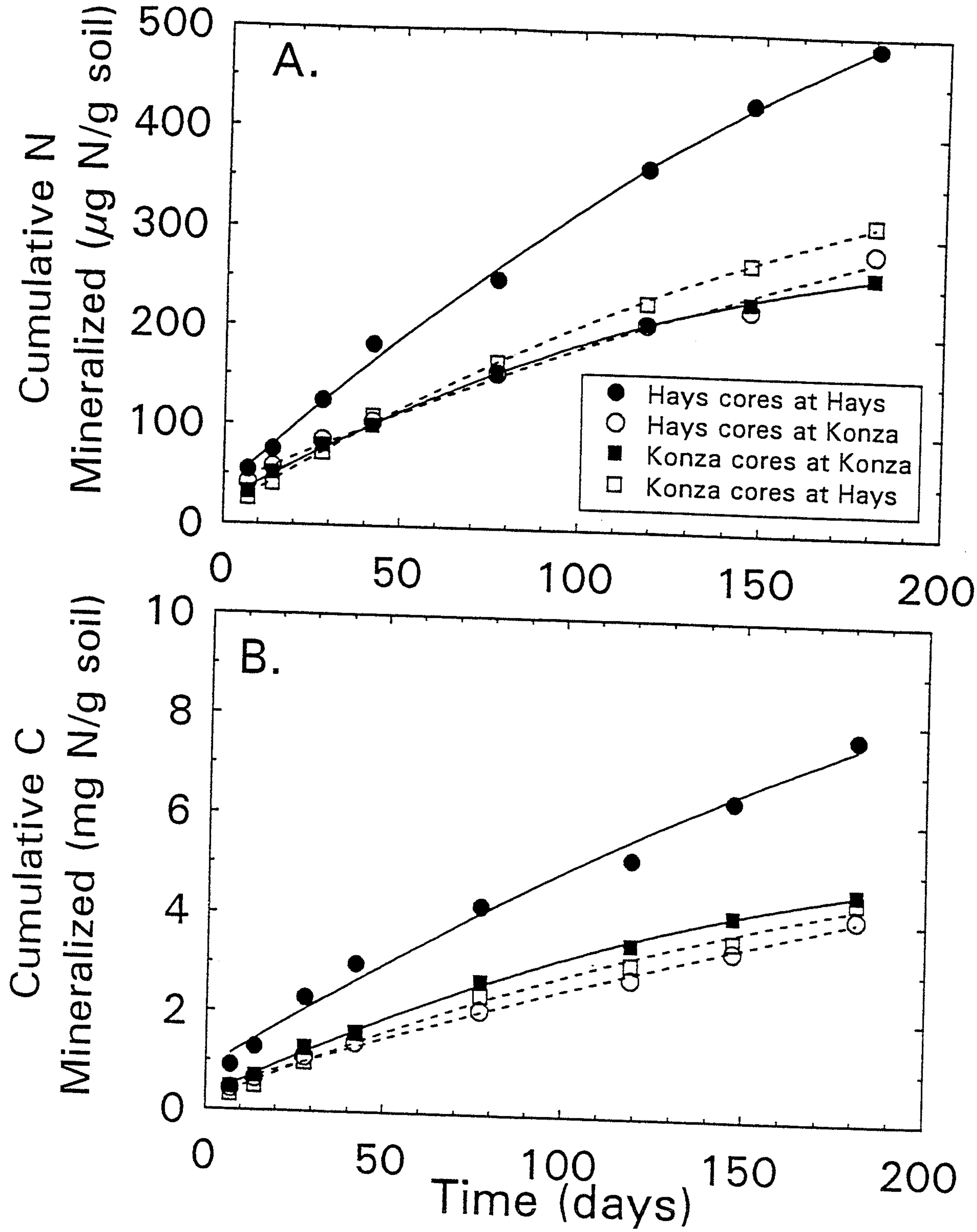


Fig. 2. Potentially mineralizable soil N (Fig. 1A) and soil C (Fig. 1B) in 0-5 cm deep soils from intact cores collected in May 1994. Circles are soil cores originally from Hays and squares are coil cores originally from Konza. Solid symbols represent soil cores which had been left at their site of origin, while open symbols represent cores reciprocally transplanted in November 1993 (see text for explanation). Note the significant decline in cumulative N and C released from Hays cores transplanted to the Konza site

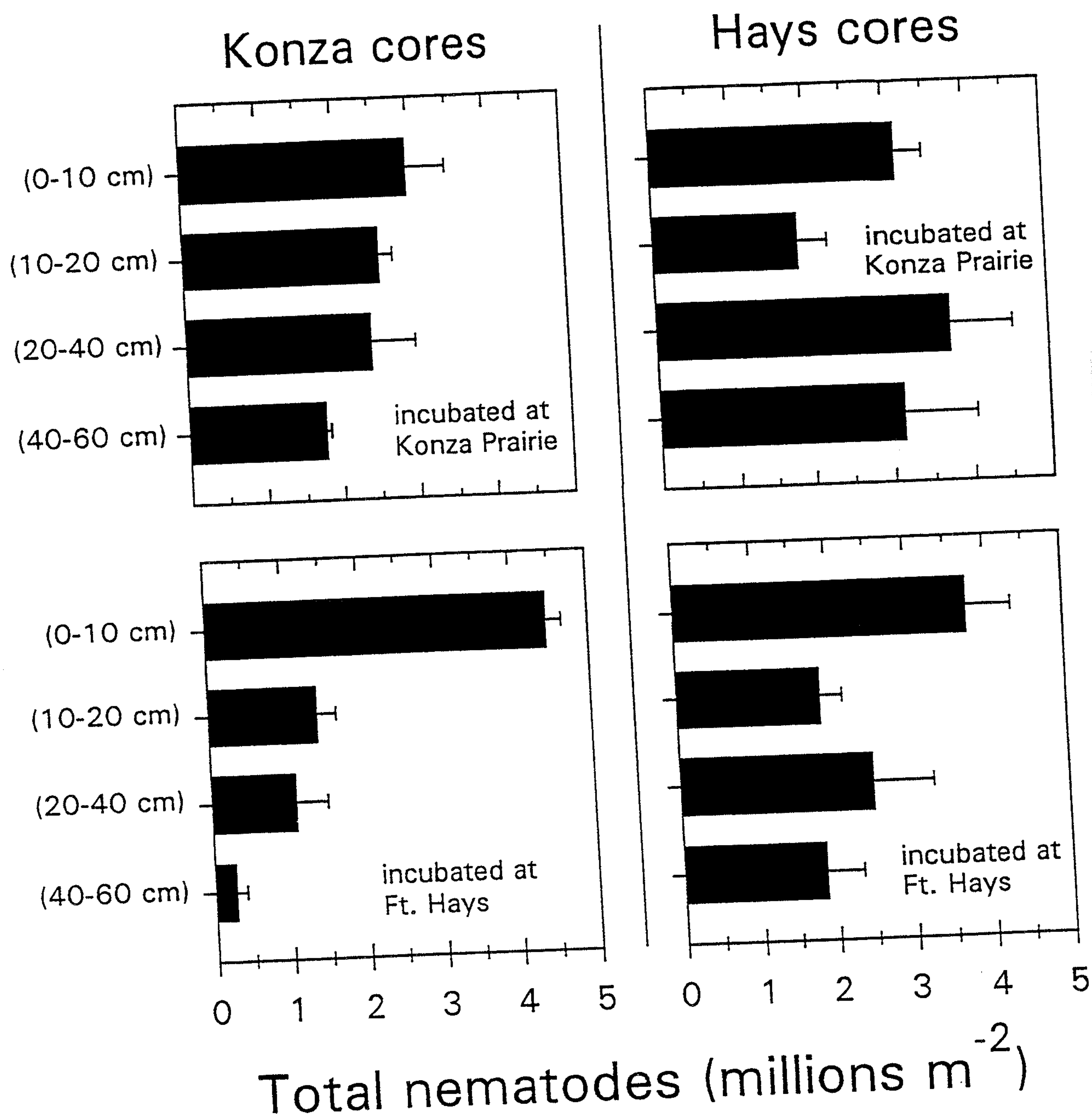


Fig. 3. Densities of total soil nematodes by depth in cores collected in November 1994, one year after the start of the reciprocal core transplant experiment. There was a significant core origin × depth interaction, indicating significant differences, by depth, between cores from Hays and Konza. Effects of transplanting cores were not yet significant, although there appear to be shifts in depth distribution of nematodes in Konza cores transplanted to the Hays site.

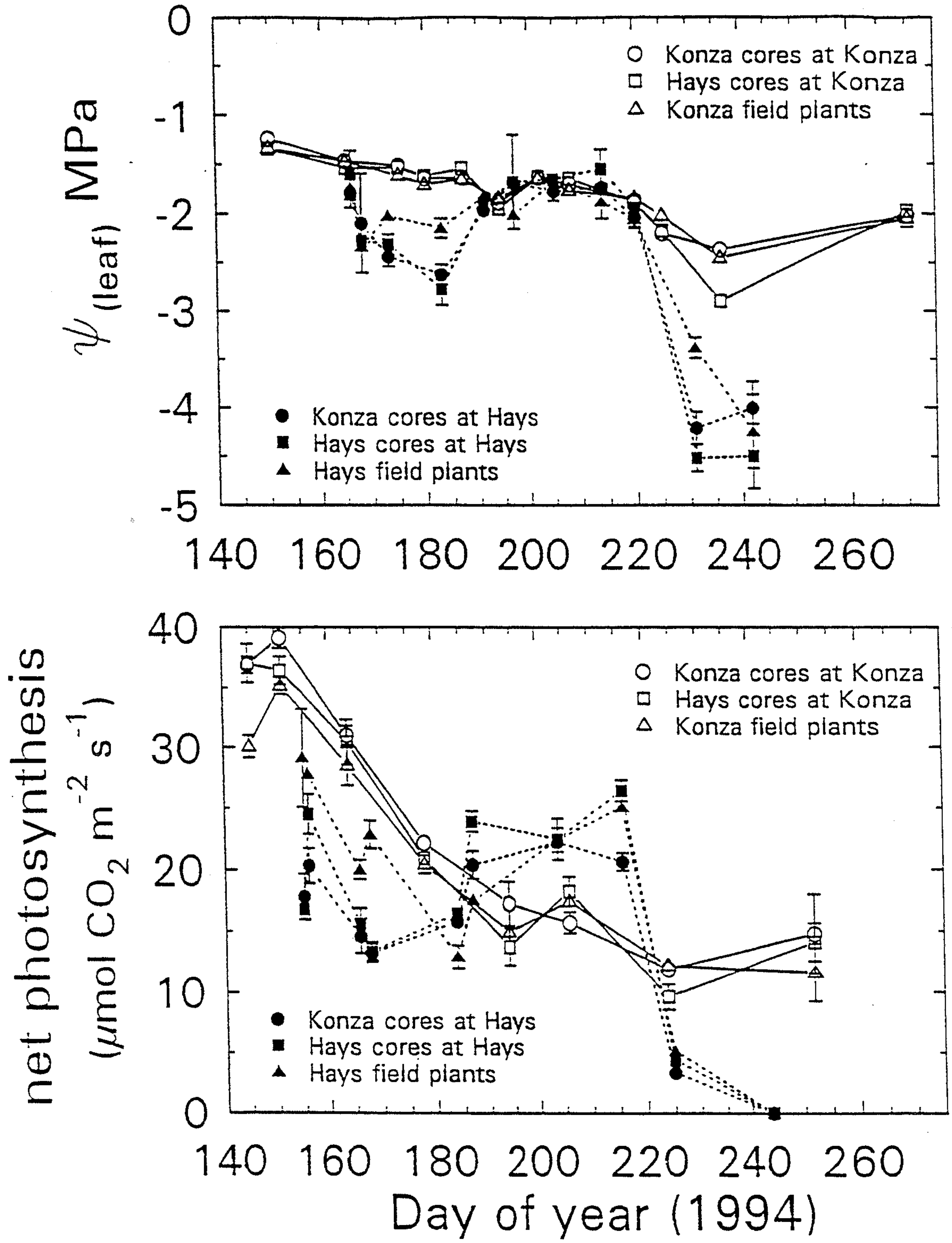


Fig. 4. Seasonal (1994) ecophysiological responses of big bluestem (Andropogon gerardii) in the reciprocal core transplant experiment (see text for explanation). Top panel: mid-day leaf water potentials. Lower panel: Leaf-level net photosynthesis.

Detection of Climate Change Using Living and Extinct Diatom Floras

Kyle D. Hoagland and Stephen G. Ernst
University of Nebraska-Lincoln

Objectives: The objectives for year two of the project were to (1) complete the DNA characterizations using RAPD-PCR, (2) analyze these characterizations statistically and to (3) characterize selected clones physiologically under a broad range of temperatures. This characterization will ascertain the thermal plasticity of these clones to determine the impacts of these adjustments or adaptations on primary productivity and higher trophic levels in lakes in the Great Plains.

Products: The products of year two are the genetic characterizations of 126 clones incorporating 154 bands from 5 primers. A cluster program was run on SAS statistical package and a dendogram was generated from the Average Linkage Cluster Analysis. Thermal characterizations will be analyzed statistically using ANOVA.

Approach: The selection of clones to utilize in the statistical analysis was made on the completeness of banding results by eliminating clones from the cluster analysis if bands were not generated in all of the primers. Freelance was used to translate the dendogram based on the distance matrix from SAS cluster program.

The physiological temperature characterizations utilize the Turner Design Model 10-AU-000 fluorometer in nondestructive sampling procedures. Clones are kept in culture in 300-ml flasks in soil water medium augmented with Alga-gro nutrients (Carolina Biological Supply). Clones are acclimated to Pyrex borosilicate glass tubes with polypropylene screw caps for two 4-d periods with transfer of 10% volume between the acclimation periods and at the beginning of the complete growth sequence. Tubes were initialized to the various temperatures in gradual steps with a 4-d acclimation period to each temperature before the final analyses are attempted. Tubes were read daily during the acclimation period and during the one-week run. Growth rates were calculated using the formula):

$$\text{Growth rate} = \text{Ln (fluorescence on day 1 / fluorescence on day 0)/Ln(2)}.$$

Results to Date: The goal of year two of our research has been to provide genetic information from the genetic markers generated during year one and to provide information on genetic variability among algal thermal ecotypes across a broad latitudinal temperature gradient traversing the Great Plains. A total of 126 clones have provided 149 different genetic markers with each of the five primers selected for statistical analysis. Genetic variation was quite large, with only three exactly duplicate marker patterns from all clones. Twenty-seven clusters were determined by the SAS Cluster procedure. Cluster patterns conform closely to state sampling locations, which is not surprising since the sampling sites have a disjunct distribution. The Texas clones cluster as a separate branch off the main cluster grouping and are thus the most distinct from the rest of the clones from the more northerly states. Other state locations cluster out into from two (Kansas) to ten South Dakota distinct clones. This variation is also a function of the number of successful isolates from the original sampling period and from the robustness of the individual clones in culture.

The genetic variation exhibited by the clones in the RAPD-PCR procedure is also mirrored in the thermal characterization procedures. Clones from the same geographical sampling site can show markedly different responses to the temperature regimes. These differences are shown in the growth response during the experimental period. The Texas clone depicted here shows an optimal growth rate in the temperature range from 26-29°C. The Manitoba clone shows optimal growth rate from 8-26°C and a steep decline at higher temperatures.

Presentations:

Jensen, Susan I., Raymond J. Lewis, Kyle D. Hoagland, Stephen G. Ernst, Virginia I. Miller and Dean M. DeNicola. 1995. Genetic variation in *Fragilaria capucina* clones along a latitudinal gradient. Phycological Society Meeting, Breckenridge, Colorado.

Publications:

Hoagland, Kyle D., Stephen G. Ernst, Susan I. Jensen, Raymond J. Lewis, Virginia I. Miller and Dean M. DeNicola. 1995. Genetic variation in *Fragilaria capucina* clones along a latitudinal gradient across North America: a baseline for detecting global climate change. Proceedings of the Thirteenth International Diatom Symposium in Diatom Research (in press)

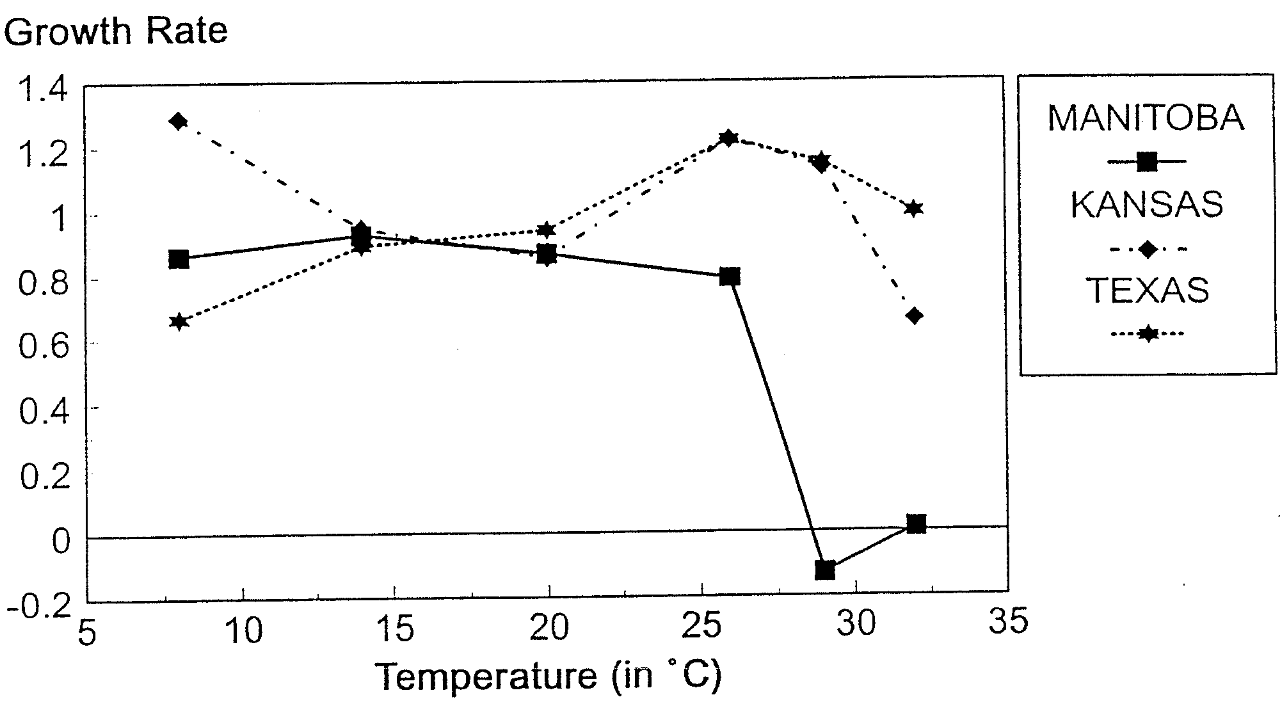


Figure 1. Dendogram showing relationships between groups of clones. Horizontal lines from the right show the relationship of clones generated from the Cluster procedure. Vertical lines along the left axis delineate locations of the various clusters. Clones tended to cluster by locations, but, apart from Texas and North Dakota, were closely related to each other.

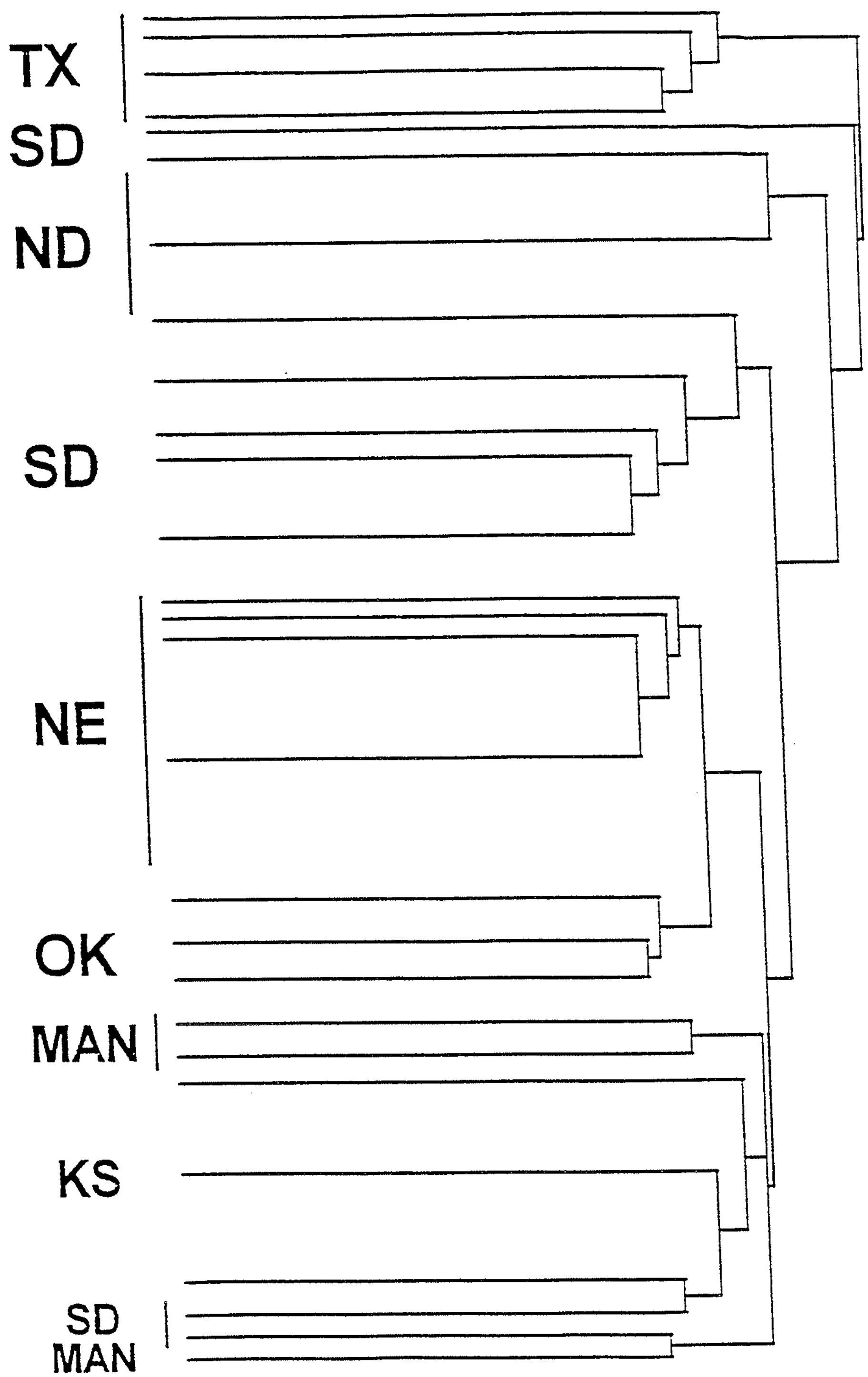


Figure 2. Three representative clones showing highest growth rates for a one-week time period at six temperatures. In these clones, Texas (evenly dotted line) shows tolerance for the entire temperature range, but a maximum growth rate at the higher temperatures. Kansas, in the unevenly dotted line) shows good tolerance for the cooler temperatures, but a markedly decreased tolerance for the temperatures above 29°C. Manitoba, the northernmost clone, showed optimal growth rates at the lower temperatures, but died at the two higher temperatures.

Natural Responses of Shallow Lakes and Wetlands for Measuring and Analyzing Impacts of Climatic/Environmental Change

Donald C. Rundquist, David C. Gosselin, Ram M. Narayanan; University of Nebraska-Lincoln
Jeffrey S. Peake; University of Nebraska at Omaha
Douglas G. Goodin; Kansas State University

Objectives: 1) Perform historical analyses of hydrological, biological, and climatological signals and fluxes relating to selected lake/wetland systems in the Nebraska Sand Hills to establish base-line conditions against which "environmental variance" can be assessed; 2) evaluate the relationships between/among hydrological, biological, and climatological signals and fluxes as they relate to lake/wetland processes in order to facilitate the modeling of environmental conditions, given selected climate scenarios; 3) investigate the variability over time in the flows of energy and carbon production; and 4) measure and map the spatial distributions of conditions related to the natural production of trace gases.

Products: A final project report, symposium presentations, papers published in peer-reviewed journals, and an assortment of maps and graphs of selected parameters measured over time (available to interested parties upon request).

Approach: The approaches vary per objective, but are oriented primarily to analyses of available historical climatological and groundwater-level data, and on image analysis of remotely acquired data from (principally) the Landsat Multispectral Scanner (MSS), the Landsat Thematic Mapper (TM), and the European Space Agency's ERS-1/-2 synthetic-aperture radar instrument. Some attention is also being given to the recording of field data at selected sites; e.g., lake elevation, water temperature, spectral reflectance, and vegetative biomass.

Results to Date: Developing Relationships Between Hydrological and Climatological Signals and Fluxes To recognize long-term impact(s) of potential environmental change on Sand-Hills lake/wetland systems, it is necessary to develop hydrological, biological and climatological databases, on various time scales. We have obtained and analyzed historical data on lake-surface areas (from satellite images), lake elevations, groundwater elevations, precipitation, and selected climatic parameters for the two primary study sites, the Crescent Lake (CLNWR) and Valentine National Wildlife Refuges (VNWR). Because of the superior spatial and temporal density of data at the former location, however, most of our work to date is focused there.

Preliminary findings confirm the suggestion of Rundquist et al. (1987) that fundamental relationships exist among the timing and amounts of precipitation, fluctuations in groundwater levels, and both the pool elevations and surface areas of individual lakes. We will continue to refine and develop subtle details of such connections for various lakes in the primary study sites, but the establishment of these linkages allows remote monitoring of hydrologic conditions for hundreds of Sand-Hills lakes lacking groundwater-recording instrumentation.

Forty-two Landsat-MSS scenes covering the Western Sand Hills have been georeferenced and processed to correct for changing solar-illumination angles. Figure 1 summarizes the total lake-surface area for the 130 study lakes (combined) for each of the 42 images. The dashed line (A on graphic) represents the average total surface area for the 42 dates. Although a comparison with daily climatic data will not be completed until remaining scenes have been processed, some interesting points can be noted. For example, the image date of August 4, 1980 (B) is the lowest total lake-surface area found to date. Examination of climatic data from the nearby Oshkosh and Dalton stations reveals that the precipitation from March 1, 1980 to August 4, 1980, was approximately 4 inches below normal. In contrast, the May 7, 1987 scene (C) was acquired after 3.96 inches of precipitation (over a four-day period) occurred at the CLNWR. This latter scene contains the maximum amount of lake-surface area to found to date.

Additional patterns can be seen in Figure 1, especially for 1981 and 1983, when numerous good Landsat-MSS scenes were available to us. Both years show a brief increase in lake-surface area during the early portion of the growing season, followed by a decrease in surface area, and ending in October with a slight increase in surface area. The region is characterized by a precipitation maximum in late Spring/early Summer, which is indicated by the early maximum lake-surface area shown in Figure 1. Evapotranspiration for the region tends to increase during the Summer months with a definite decrease in precipitation, a tendency also supported by the surface-area-estimation curve. The slight rebound in lake area during October could be caused by a combination of increasing precipitation and, more importantly, decreasing evapotranspiration. The latter would allow for precipitation and inflow from below-ground sources to recharge the lakes.

Figure 2 allows comparison of the total surface area of the 130 lakes selected for study and all standing water (including "ephemeral ponding") in the entire study area. The trends of the two curves are similar, with minor exceptions, due probably to the fact that the lakes tend to be better connected to underground water, while the ephemeral ponds are obviously not.

We have begun interpretive modeling to gain insight into the controlling parameters affecting the seasonality of groundwater-flow patterns around the Roundup-Island Lake System, at the CLNWR. In support of this activity, we installed instrumentation to obtain high-density temporal and spatial data along a transect from Roundup to Island Lake. Data include groundwater elevation, relative humidity, ambient air temperature, and precipitation (e.g., see Figure 3). Sampling rates have varied from one-half to every four hours, and results are quite instructive.

The model that we are applying is the recent modification of the widely used USGS groundwater flow model, "MODFLOW," by Cheng and Anderson (1993) to include fluctuating lake-surface water levels. The performance of the MODFLOW lake package has been verified. Changes in lake area, documented using Landsat-MSS images, are due to variations in the input and output components of the water balance of the lake. Therefore, we have developed a finite-element-model grid to correspond with the Landsat-MSS image resolution of 79 by 79 meters. Our current modeling efforts are focusing on the seasonal dynamics of groundwater flow in the Roundup-Island Lake system as a function of changes in the water balance.

Results to Date: Wetland Vegetation A second area of our research includes using well-established remote-sensing and digital-processing techniques to analyze both current and archived data acquired over the wetland vegetation at our study sites. Specifically, for the CLNWR site, we have determined that individual wetland species cannot be identified using the current 80- and 30-meter spatial resolutions of the MSS and TM, even though our field-spectroradiometer data for individual species indicate potential for spectral separability. Therefore, we are currently attempting to digitally classify and measure the spatial extents of wetland communities in the Sand Hills, rather than species. We have detected and mapped changes in vegetative greenness of communities at various times from 1972 to the present, as previously reported. We are also currently attempting to calibrate satellite measures of above-ground biomass of wetland vegetation with in-situ measures. Our goal is not only to relate these parameters to hydrological and climatological data but also to link findings to the on-going trace-gas research of other NIGEC investigators.

In addition, we are beginning to develop methods for incorporating long-wavelength, orbital radar into analyses of optical data. Preliminary results indicate that C- and L-band radar are sensitive to changes caused by the growth and flowering of emergent wetland species. Surprisingly, we have also learned that detection of submergent communities in shallow lakes seems possible with C-band data. Additional goals are to use orbital radar to document the presence/absence of standing water beneath fully developed wetland canopies, and to monitor soil-moisture patterns around lake systems (as well as enhance digital classifications of wetland vegetation).

Students Participating in Various Aspects of this Project (*=NIGEC funding): Rod Fraser (MA), UNO; Rolland Fraser (PhD), UNL; Mahabaleshwara Hegde*(0.5 FTE) (MS), UNL; Mohan Khisty*(0.5 FTE) (MS), UNL; Bryan Leavitt*(0.5 FTE) (PhD), UNL; Stuart McFeeters (PhD), UNL; Mahtab Lodhi (PhD), UNL; Steve Payton*(0.5 FTE) (PhD), UNL; Diana Reehoorn (MA), UNO; Brian Tolk (MA), UNL; Asad Ullah (PhD), UNL, and Mike Wiezerbowski (MA), UNO. Some funding support for these students comes/came from other agencies including NASA, EPA, and EOSAT Inc., but all are involved in various aspects of our research program aimed at remote sensing of surface waters and wetland vegetation.

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Han, L., D.C. Rundquist, L.L. Liu, R.N. Fraser and J.F. Schalles. 1994. The spectral responses of algal chlorophyll in water with varying levels of suspended sediment. International Journal of Remote Sensing, 15(18):3707-3718.

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Khristy, Mohan J., David C. Gosselin, and Donald C. Rundquist. 1995. Characterizing a groundwater-lake system in the Nebraska Sandhills using a mass balance approach and remotely sensed data. Presented at the annual meeting of the Geology Society of America, North-Central/South-Central Sections, Lincoln, Nebraska.

Fraser, R.N., and D.C. Rundquist. 1994. Thematic Mapper spectral data and the spatial distribution of classes within Nebraska Sand Hills lakes. Presented at the annual meeting of the American Society of Limnology and Oceanography, Miami, Florida.

Fraser, R.N. 1995. Water quality along an alkalinity gradient with remote sensing. Presented at the annual meeting of the Association of American Geographers, Chicago, Illinois.

Rundquist, D.C., L. Han and R.N. Fraser. 1994. Hyperspectral remote sensing of sedimentary turbidity. Presented at the annual meeting of the American Society of Limnology and Oceanography, Miami, Florida.

Yang, W., and D.C. Rundquist. 1995. Modeling bottom effects on water reflectance. Presented at the annual meeting of the Association of American Geographers, Chicago, Illinois.

Payton, Steven, Donald C. Rundquist, Diana Reehoorn, Jeffrey Peake, and John Schalles. 1995. Remote sensing of submerged aquatic macrophytes. Presented at the annual meeting of the Association of American Geographers, Chicago, Illinois.

Tolk, Brian L., and Luoheng Han. 1995. The bottom effect and spectral responses of water at various turbidity levels. Presented at the annual meeting of the Association of American Geographers, Chicago, Illinois.

Wetland Lake Area Estimations Using
NDWI [(GREEN-NIR)/(GREEN+NIR)*255]

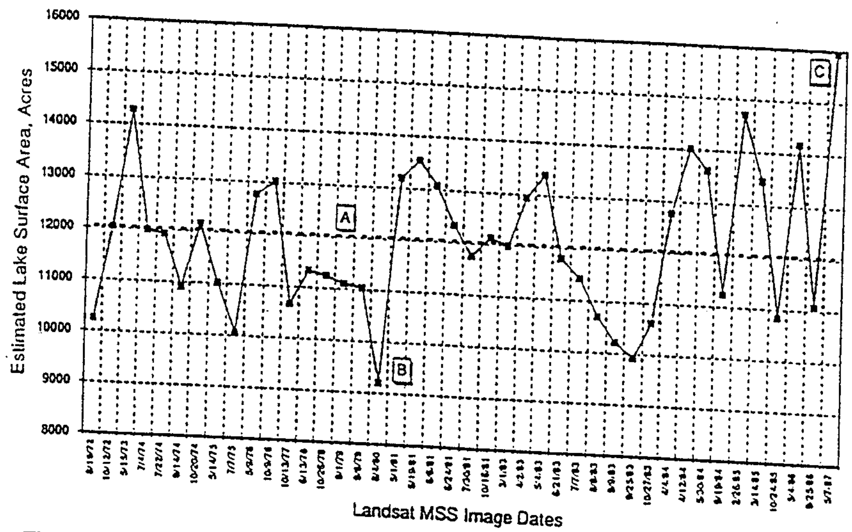

Figure 1: Combined surface areas for 130 study lakes, per image date.

Open-Water Surface Area Estimations
Using NDWI (GREEN-NIR)/(GREEN+NIR)*255

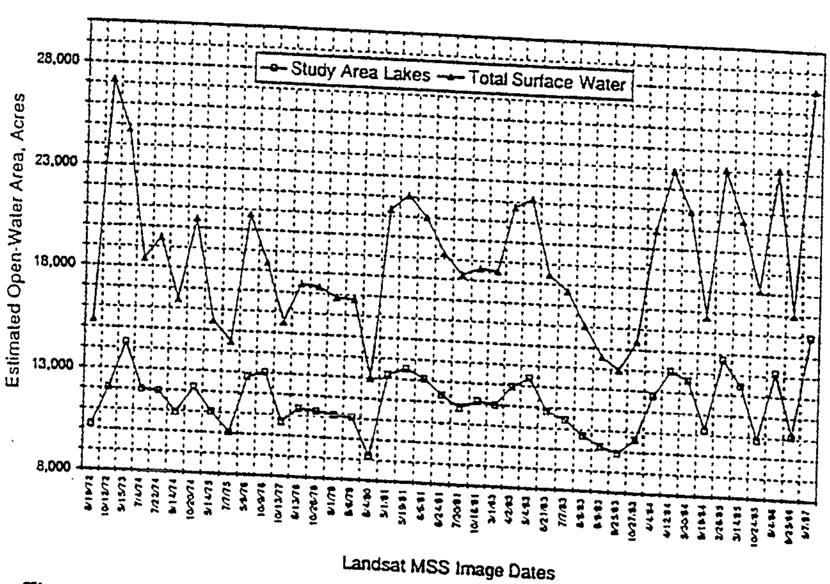

Figure 2: Comparison of combined surface areas for 130 study lakes
and all water standing in study area, per image date.

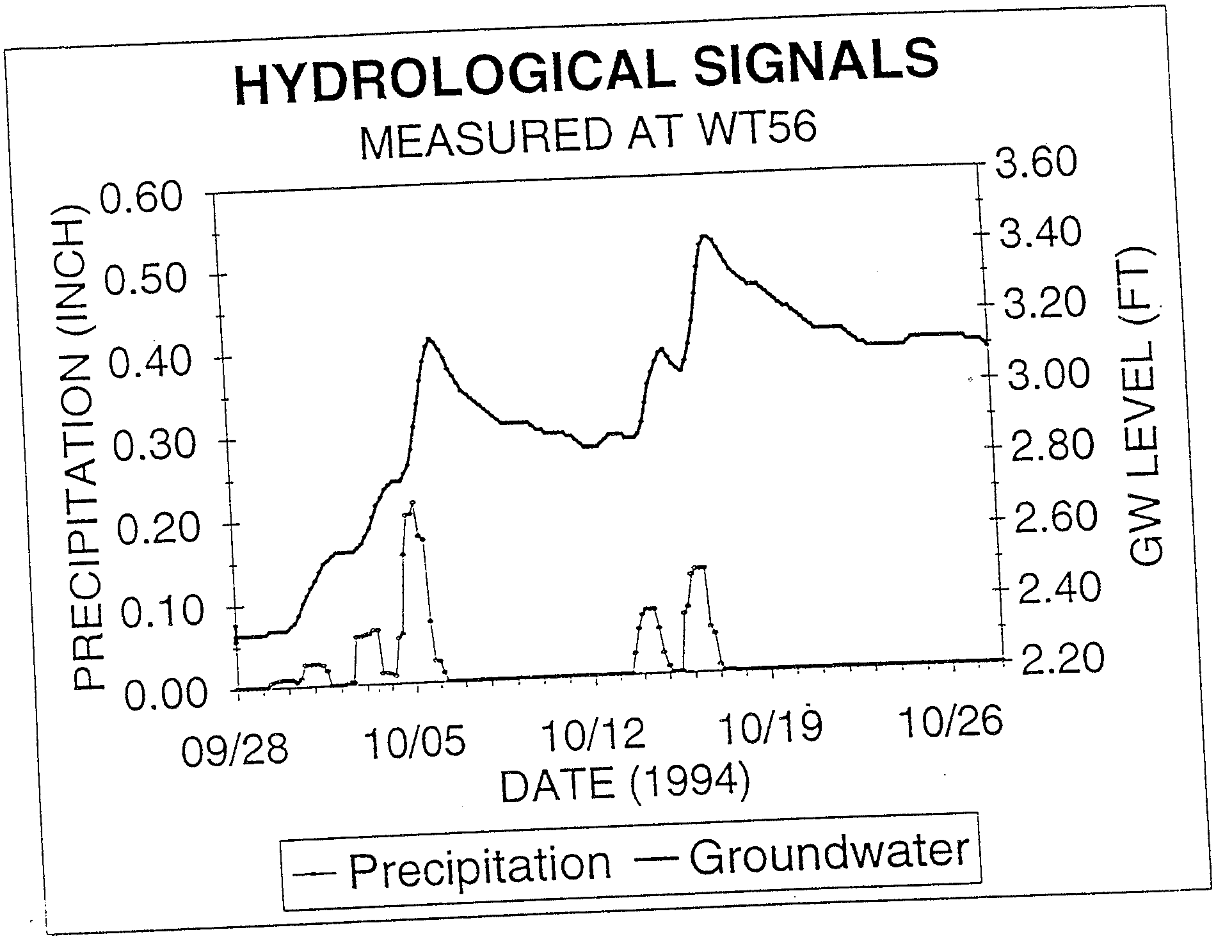

Figure 3: Example of in-situ data collected in the Roundup/Island Lake transect.

Space-Time Local Hydrology Influenced By Changing Climatology: Disaggregation, Prediction and Comparison

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Objectives: A stochastic downscaling technique will be developed and applied for estimating local/regional hydrological quantities reflecting global climate change. Specific objectives include: (1) Relate the arrival rate of atmospheric circulation patterns of a given type to the probability of space-time hydrological variables. (2) Provide a tool for using existing synoptic outputs of GCM for prediction of space-time hydrological variables at a regional or watershed level. (3) Compare and evaluate the climate change impact on hydrological variables over several regions of the United States and Europe.

Products:

1. A validated methodology will be available to estimate local/regional hydrological impacts of global climate change. The methodology has been and will be published in refereed journals or conference proceedings (Bardossy et al. 1995; Bardossy et al. 1993; Bartholy and Duckstein, 1994; Bogardi et al. 1994b; Bogardi et al. 1994c; Bogardi et al. 1994a; Bogardi et al. 1994d; Duckstein et al. 1994a; Galambosi et al., 1995; Matyasovszky et al. 1993a; Matyasovszky et at., 1993b; Matyasovszky et al. 1994a; Matyasovszky et al. 1994b; Matyasovszky et al. 1994c; Ozelkan et al. 1994a, 1994b; Pesti et al. 1994; Weidinger et al. 1994).

2. Quantitative information on the expected hydrological impacts of climate change will be available for the regions considered.

3. Computer codes will be available upon request to facilitate the application of the methodology to other regions. Although these codes have been used extensively by us and by our cooperative partners, their successful application will require a modest familiarity with the methodology.

Approach:

Circulation Pattern (Cp) Data. Three types of daily Cp data are used.

1. Historical data are represented by the National Meteorological Center (NMC) grid point analyses of the height of 500 hPa pressure fields available from the National Center for Atmospheric Research (NCAR). The analysis is based on daily values (12^{00} UT) at 40 points on a diamond grid covering the sector 25 -60 N, 80 -125 W for the period January 1948-June 1989, which covers the central USA.

2. A 10-year long data series for the same pressure level has been obtained from the output of MPI (Max Planck Institute for Meteorology, Hamburg, Germany) and CCC (Canadian Climate Centre) GCMs corresponding to the $1xCO_2$ scenario.

3. An analogous series has been obtained from the $2xCO_2$ scenario.

Compiling Circulation Pattern (Cp) Types.

We used principal component analysis (PCA) coupled with k-means because a conjunctive use of these techniques usually provides the most separable system of clusters with the most concentrated clusters (Bartholy, 1992). We also used a fuzzy rule- based approach (Bardossy, et al. 1995; Ozelkan, et al. 1994b).

Relating Local Climate to Cp Types.

To reproduce the space-time statistical structure of local climatic factors, a suitable model should be chosen. Autoregressive processes represent a well-developed and commonly used tool to model time series. They have been developed principally for Gaussian processes, but climatic factors do not usually follow a Gaussian distribution. Therefore, it is desirable to construct a transformation establishing a relationship between the distribution of a local climatic factor and a normal distribution. Let the vector $\mathbf{Z}(t)=(Z(t,u_1), Z(t,u_2),..., Z(t,U_k))$ represent a daily climatic variable at locations $u_1, u_2,..., u_k$ and time t and let $\mathbf{W}(t)$ be a K-dimensional normal random vector at time t. We suppose for simplicity that each component of the vector $\mathbf{W}(t)$ has unit variance. The time dependency of $\mathbf{W}(t)$ is described using first order autoregressive (AR(1)) processes. The transformation of the random vector $\mathbf{Z}(t)$ into the normal vector $\mathbf{W}(t)$ depends on the climatic variable under consideration as shown for rainfall in Matyasovszky et al. (1993b) and for temperature in Matyasovszky et al. (1994b).

Special Consideration for the $2xCO_2$ Data.

We have shown that the Cp characteristics within a given Cp type may change which means that knowledge of the Cp type alone may not be enough and that additional parameters have to be introduced to describe Cps under climate change. We used the geopotential height of a pressure level as an indicator of the atmospheric pressure and temperature. The anticipated warming due to the increasing concentration of CO_2 gas is accompanied with the expansion of atmosphere so that pressure levels are located at larger heights. The concept to correct for systematic over- or underestimation of the geopotential heights is as follows. The annual cycle, i.e., changes in the expectation of geopotential height within the year is considered as an analogy of the difference between geopotential heights corresponding to the present and $2xCO_2$ climates. The relationship between parameters of the daily climatic variables and spatial average height is described using historical data and is then used to estimate the effect of climate change on these local variables. To this end, we investigate how the probability distribution of local climatic variables (conditioned on Cp types) at a given location depends on the actual height of the 500 hPa pressure field.

Probability distributions are estimated corresponding to the $1xCO_2$ and $2xCO_2$ monthly mean heights of the 500 hPa pressure field, and the probability distribution calculated from the whole historical data set is adjusted according to the difference between the two above mentioned distributions (CO_2 case). Specific forms of this adjustment are described for precipitation in Matyasovszky et al (1993b) and for temperature in Matyasovszky et al. (1994b).

Results to date:

1. A general framework for studying hydrologic uncertainties related to climate change has been developed in Duckstein and Parent (1993), Duckstein (1994), Duckstein et al. (1994a) and Waterstone et al. (1993)

2. Nine stations for analyzing precipitation data and four for temperature data have been selected in eastern Nebraska where two seasons are distinguished for precipitation and each month is examined separately for temperature. Ten stations for analyzing both precipitation and temperature data over four seasons have been selected for the Arizona case study, because of the variety of climatic zones in the state. Other data, such as wind and evapotranspiration are being gathered. Stations in New Mexico are also being selected as a function of length and reliability of records.

3. Daily atmospheric circulation patterns (Cp) have been classified objectively or automatically using principal component analysis (PCA) with the k-means approach. For the Great Plains, this procedure yields nine Cp Types in both the winter and summer seasons (Bogardi et al. 1993). Cp's have been classified subjectively on the basis of the types defined in Bradley et al. 1982 for the

central Arizona case for the three seasons (summer, autumn, winter) in which watershed hydrology can be simplified; namely, without mix of rain and snowmelt (Duckstein et al. 1993). Fuzzy rule-based and neural-net based classification of the 500 hPa Cps has been constructed for Western Europe and then the two Western basins under consideration, that is, central Arizona and the Upper Rio Grande Valley (Bardossy et al. 1995; Bartholy and Duckstein, 1994; Galambosi et al. 1995).

4. Precipitation over nine Nebraska sites and ten Arizona sites have been conditioned on the time series of Cp types and then simulated using a split sample technique with historical data. On the basis of the model described in Matyasovszky et al. 1993a, most encouraging results have been obtained on this dependence of space-time precipitation upon time series of Cp types.

5. A ten-year time series of daily Cps obtained from the output of two GCMs (Canadian Climate Center and Hamburg Model) have been analyzed in the cases of $1xCO_2$ and $2xCO_2$ using the same techniques as for historical data (Bogardi et al. 1994a; Galambosi et al. 1995). No significant difference in either typology (by CPA) or Markov properties (transition probabilities from one type to another one) could be found for either season (summer or winter).

6. In order to utilize the above GCM results, the average height of the 500 hPa Cps has then been taken as a third characteristic of Cps under climate change, leading to a clear differentiation between the $1xCO_2$ case (historical or GCM produced) and the $2xCO_2$ case (GCM produced) in Nebraska (Matyasovszky et al. 1993a).

7. Precipitation over the Nebraska sites appears to exhibit different but site specific behavior in the $2xCO_2$ versus $1xCO_2$ cases; overall, there is only a slight increase of mean precipitation but the variability of precipitation increases substantially; namely, fewer events with greater rainfall depths are found to occur (Matyasovszky et al. 1993b). Results in Arizona and New Mexico are very station dependent.

8. Floods in Central Arizona have been conditioned on daily Cps defined subjectively occurring over an optimum time window before the flood event, found to be three days (Duckstein et al. 1993). Extreme precipitation is also being investigated (Ozelkan et al. 1994).

9. The Cp output of two different GCMs has been used to downscale temperature and rainfall in eastern Nebraska, Arizona and New Mexico. Both GCMs resulted in similar tendencies but somehow different local responses to climate change (Matyasovszky et al. 1994a; Duckstein et al. 1994b).

10. A methodology for predicting various drought indices (PDSI and Bhalme-Mooley Index) under climate change has been developed and applied to eastern Nebraska (Bogardi et al. 1994a, 1994b) and New Mexico (Pesti et al. 1994).

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Observational and Numerical Study for Interannual and Interdecadal Variability of the Atmospheric Circulation

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Objective: The primary goal of this project is to examine effects of the Pacific sea-surface temperatures (SST) on the interannual and interdecadal variability of the winter and summer atmospheric circulation, and effects of doubling CO_2 on the interannual and interdecadal variability of the winter atmospheric circulation.

Approach: It was revealed by numerous studies that the long-term climate variabilities are reflected in variations of stationary eddies. For the observational study, we diagnostically analyzed the possible correlation between interannual/interdecadal variations of stationary eddies and climate variables at key locations, and performed the empirical orthogonal function (EOF) analysis of three variables. The purpose of these analyses was to explore the structure of interannual/interdecadal modes associated with stationary eddies. The data used in the observational study are OLR, COADS SST (Slutz 1985), upper-air data generated by the NMC Global Data Assimilation System (GDAS), and surface pressure-300 mb heights compiled by the NMC after World War II. For the numerical study, two types of numerical simulation with the NCAR Community Climate Model (CCM) (Williamson et al. 1987) were performed: (a) a real-time simulations with the 50-year (1943-1992) SST (from the COADS) and (b) a 30-year simulation with double CO_2.

The following tasks were pursued: (1) analysis of the three-dimensional structure of the interdecadal variation mode with the NMC data for the Northern Hemisphere and the Australian data for the Southern Hemisphere, (2) diagnostic analysis of the 50-year real-time SST simulation of the NCAR CCM to determine the effect of the Pacific SST on the interdecadal variation of the wintertime atmospheric circulation, (3) diagnostic analysis of observational data to explore the effect of the Pacific SST variation on the interannual variation of summertime stationary waves over the North Pacific basin, (4) interannual variation of the global relative atmospheric angular momentum (RAM) and (5) the interannual variation of global RAM in the double CO_2 simulation.

Results to Date: The major findings related to the interdecadal variation of the Northern Hemisphere (NH)- wintertime circulation are summarized as follows: (1) The interdecadal variation of the NH winter circulation in the past four decades is associated with the amplification of stationary waves: the deepening of the three major stationary troughs and the weak amplification of the three major stationary ridges. (2) With some simple statistical analyses, two interdecadal variation modes were identified in the NH winter circulation: the so-called *Pacific* and *Atlantic* modes. The former mode exhibits a spatial structure similar to the Pacific-North America teleconnection pattern, while the latter mode possesses a spatial structure like the North-Atlantic Oscillation. Furthermore, although these two interdecadal modes are characterized by an equivalent barotopic structure, and have the same linear trend in their interdecadal evolution, they oscillate *independently*. The Pacific interdecadal mode oscillates coherently with the interdecadal mode of the North-Pacific SST. In contrast, the Atlantic interdecadal mode does not oscillate in a coherent way with that of the North Atlantic SST. (3) The Pacific interdecadal mode is associated with a meridional shift of the North Pacific jet stream and the associated cyclone activity of the Pacific storm track. The Atlantic interdecadal mode is associated with a slight meridional shift of the North Atlantic jet stream, but with enhanced cyclone activity only along the Atlantic storm track.

The major findings of the interdecadal variation of the Southern Hemisphere (SH) atmospheric circulation in the past two decades (1972-1992) are: (1) the interdecadal variation of the SH circulation in the past two decades was characterized by a latitudinal stratification in which the high-latitude circumpolar trough deepened and the midlatitude high strengthened; (2) this interdecadal variation exhibited an equivalent barotropic structure; (3) the winter and summer spatial structure of the SH interdecadal variation persisted in the ensuing transition seasons; and (4) the cyclone activity was enhanced over the circumpolar low centers, following coherently their interdecadal deepening. It is hypothesized that the interdecdal SST change is one of the possible mechanisms that can induce the interdecadal change of the NH winter circulation. To test this hypothesis, two multi-decade (1946-92) climate simulations were performed with the R15 resolution of the NCAR CCM1: one incorporating the 12 calendar month climatological SSTs, the other using the real-time SSTs. By contrasting the results of these two climate simulations, the effect of SST anomalies on the interdecadal change of the NH winter circulation was found to induce (1) the equatorward expansion of the circumpolar vortex, (2) the deepening of three climatological troughs, and (3) three interdecadal variation modes of stationary eddies: Pacific/North America (PNA), PNA west (PNAW), and North Atlantic (NA) modes. These three interdecadal modes were found to be equivalent barotropic in their vertical structure. Horizontally, both the PNA and PNAW modes exhibited a teleconnection pattern over the Pacific/North American region, while the NA mode possessed a north-south three-cell structure over the Greenland/North Atlantic region. The temporal variations of these three modes consisted of a decadal trend and 15-20 year low-frequency oscillations. The interdecadal variation of general circulation statistics is regulated by the interdecadal variation of the atmospheric circulation. In the thermal field, the transient heat flux diverges out of the warm anomalies and converges toward the cold anomalies. In the dynamic field, the cyclone activity over the midlatitude storm track region is affected by the variability of the north-south wind shear, which is induced by the equatorward expansion of the circumpolar vortex.

A teleconnection wave train (originating from the western tropical Pacific) along the northern rim of the Northern Pacific is evident from (1) the correlation coefficients between the upper-level height departures from the multi-summer mean and the SST anomalies averaged over the eastern tropical Pacific (NINO-3) region and (2) the composite charts of these upper height departures for the summers following the El Niño-Southern Oscillation (ENSO) events in the past 15 years. This stationary wave train was separated into the long-wave (wavenumbers1-3) and short-wave (wavenumbers 4-15) regimes. The long-wave train propagates from the western tropical Pacific to the Arctic along the western rim of the North Pacific. The short-wave train propagates from the northwestern Pacific to North America along the northern rim of the North Pacific. The long-wave train is related to the interannual variation of the East-Asian monsoon, while the short-wave train may be related to the interannual variation of the summertime North-American circulation.

The interannual variation of the global relative atmospheric angular momentum (RAM) coincides with the Southern Oscillation index and the NINO3-SST anomalies. This interannual variation of global RAM is coherent with the poleward propagation of RAM in the following manner. The global RAM reached its minimum values when westerly anomalies emerge in the tropics and higher latitudes, and easterly anomalies appear in the tropics during the cold-ENSO phase. The global RAM gains its maximum values when westerly anomalies arrive at the subtropics of both hemispheres and are strengthened during the warm-ENSO phase. It was demonstrated that the poleward propagation of RAM results from the flip-flop oscillation of the anomalous circulations between the cold and warm ENSO events.

Since the global RAM is a sensitive indicator of the interannual variation of the atmospheric circulation, this variable was adopted to illustrate the effect of doubling CO_2 on this interannual variation in the numerically simulated climates. We contrast the global RAM between the 30-year climate simulations with single and double CO_2 concentration using the NCAR CCMOA. Based upon the global RAM time series and the anomalous circulation patterns, we found that the interannual variation in the NCAR CCM climate can be enhanced by doubling CO_2.

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Student participation:

Jau-Ming Chen 100% (the funding for this student's participation comes from a NSF grant).

The Effect of Ecosystems on Cloud Microphysics and Aerosol Distribution

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Objectives: To examine changes of ecosystems of regional, national, and global scale in a changing climate. To evaluate the relationship between ecosystem and cloud cover, and the relationship between ecosystem, cloud droplet sizes, and total cloud liquid water content.

Product: (1) Construct NDVI distribution data on the basis of ISCCP analysis. We plan to construct a NDVI distribution dataset over continental areas covering five years (July 1986 - June 1991) on the basis of ISCCP analysis. This dataset will be on the near-global scale (50°S to 50°N). This process will rely upon ISCCP analysis for its cloud products (clear, cloudy categories for the same AVHRR pixel). Such a dataset will provide simultaneous information on NDVI indices and cloud cover. Once the ISCCP cloud products have been retrieved, the production of the NDVI indices requires only a minor increase in the processing requirements. (2) Perform near-global retrieval of cloud droplet radii. To study the effect of seasonal, regional changes of ecosystems on cloud microphysics, based on the previous work of Han et al. (1994), we are processing five years of ISCCP CX data to retrieve cloud droplet sizes (July 1986 - June 1991). This period avoids Mt. Pinatubo, covers one El Niño year, and provides coverage by two polar orbiters for all but the first five months. This will allow us to determine cloud droplet sizes appropriate for different ecosystems and seasons. (3) Estimation of effect of NDVI values on cloud droplet radii. This analysis will be performed by correlating distributions of NDVI values with cloud droplet radii. The relative importance of anthropogenic aerosol and ecosystem on cloud droplet radii will be investigated by comparing more polluted regions (e.g., eastern part of U.S.) with relatively clean regions (e.g., Great Plains).

Approach: Our analysis starts with the ISCCP cloud products retrieved from AVHRR data. These results include a division of individual fields-of-view (FOVs) into "clear" and "cloudy" categories and the retrieval of cloud optical thickness values. Only "clear" pixels will be used to calculate the NDVI, thus the cloud contamination effect on NDVI can be easily minimized.

To complete the analysis of five years of AVHRR data, we are using the ISCCP CX dataset which is composed of the original radiances, sampled to about 30 km spacing, and the results of the ISCCP analysis, all at the original pixel level. Use of this dataset provides a statistical sample of the original AVHRR dataset, sufficient for producing a climatology of NDVI and cloud properties and takes advantage of the results of the ISCCP cloud detection analysis to provide an initial separation of image pixels into "clear" and "cloudy" categories.

There is no five-year period covered solely by one pair of AVHRRs; in all cases, we will need to pay close attention to intercalibration among the different AVHRR sensors. However, the NASA/NOAA PATHFINDER project is working to extend the ISCCP and other calibration results already available for Channels 1 and 4 on NOAA-7, -9, and -11 to the remaining spectral channels and to the AVHRRs on NOAA-6, -8, -10, and -12. We will be able to use these calibrations. The period selected, July 1986 - June 1991, is covered by NOAA-9 (February 1985 - October 1988), NOAA-10 (December 1986 - August 1991), and NOAA-11 (November 1988 - current).

The volume of this dataset is equivalent to six 6250 bpi data tapes per satellite per month. If dedicated processing were performed, then estimates of the CPU needed, together with tape and disk storage required, indicate that it is practical to analyze three satellite-months of data per week, requiring about nine months to process five years of data. However, once we develop the retrieval and analysis method, we can add our processing software to the other programs that will be running on the CX dataset during FY94 and 95. The resource demands of our software are smaller than those of the other analyses; but this may mean that the actual pace of analysis will be slower. This approach allows us to use the automated data handling facilities and software management system at the ISCCP Global Processing Center at NASA Goddard Institute for Space Studies, which reduces the expense of the analysis to the marginal cost of some staff time and additional data tapes. This data processing will be performed at no cost to the project.

Results to Date: *Developing retrieval scheme.* One of the ultimate targets of this proposal is to retrieve cloud droplet radii, NDVI, cloud amount at a near global scale for five years. The goal of year two of our research has been to develop retrieval scheme for the batch processing at GISS (Goddard Institute of Space Studies) ISCCP (International Satellite Cloud Climatology Project) processing center. To date, two years of data (January, April, July and October of 1987 and 1988, respectively), which have simultaneous retrieval of NDVI, cloud effective radius and cloud cover have been constructed. A production scheme has been developed and sent to ISCCP processing center to retrieve cloud properties and NDVI for the other three years. There is no problem with the time period of 1985 through 1988 which was covered by NOAA-9 satellite only. But started from 1989, NOAA-11 was the operational satellite and there are intercalibration problems for different channels between these two satellites. We are working on this now.

Result analysis. Another target of this proposal is to study the effect of ecosystems on cloud properties. The retrieved data of the two year period have been analyzed for this purpose. The results show that as an index of vegetation cover, NDVI has a positive correlation with cloud effective radius and cloud cover (see Fig.1 for example) for most regions. This means that ecosystem affects both cloud formation and cloud properties, i.e., cloud formed more often at vegetation covered areas, and these clouds tend to have larger droplet sizes. The possible mechanism involved is that vegetation plays a role in increasing water vapor content and decreasing aerosol amount in the air. Thus resulted less CCN number density and larger amount of water vapor content lead to larger cloud droplet sizes. Further investigations at regional scales are being conducted currently. We expect detailed relationship for specific regions.

Ecosystems have impact on aerosol distributions. Because aerosols are considered having direct and indirect effect on climate changes, we studied the hypothesized aerosol indirect effect by using the retrieved results. The results of variations of cloud droplet sizes are consistent with expectations for variations in aerosol loading. Statistics shows that for most regions and most times, at 0.99 significance level, southern hemisphere clouds have larger droplet sizes than northern hemisphere clouds. But this interhemispheric contrast of cloud microphysics does not lead to a corresponding interhemispheric albedo contrast as speculated by theory of indirect effect of aerosols on climate change, which proposes that smaller cloud droplet radius will lead larger cloud albedo (referred as Twomey effect by some authors). The assumption used in indirect effect of aerosols is that cloud liquid water path (LWP) has to be held constant both spatially and temporally. In reality, LWP changes dramatically at both small scale and large scale. Regional studies also show that the difference of visible reflectances is negligible between polluted cloud and unpolluted stratiform clouds with droplet sizes differing by a factor of two. As a consequence, at a near global scale, an examination of the relationship between albedo and cloud droplet sizes reveals that for most regions and most times, an indirect aerosol effect on climate is yet not detectable. However, three highly polluted regions (East coast of U.S., Europe, and Southeast China) appear to exhibit a local aerosol effect on cloud albedos.

Another analysis concerns the effect of ecosystem on surface temperature. We found a negative relationship between surface T_s and NDVI values on a near-global scale. This agrees with the local results reported by other investigators. Although it is hypothesized to be the result of fractional vegetation cover, a further investigation by using a larger data volume is needed.

Presentations:

Han, Q., W.B. Rossow, R.M. Welch and J. Chou, 1995: A near global survey of cloud particle size by ISCCP. IUGG XXI General Assembly, July 2-14, 1995, Boulder, CO (presentation)

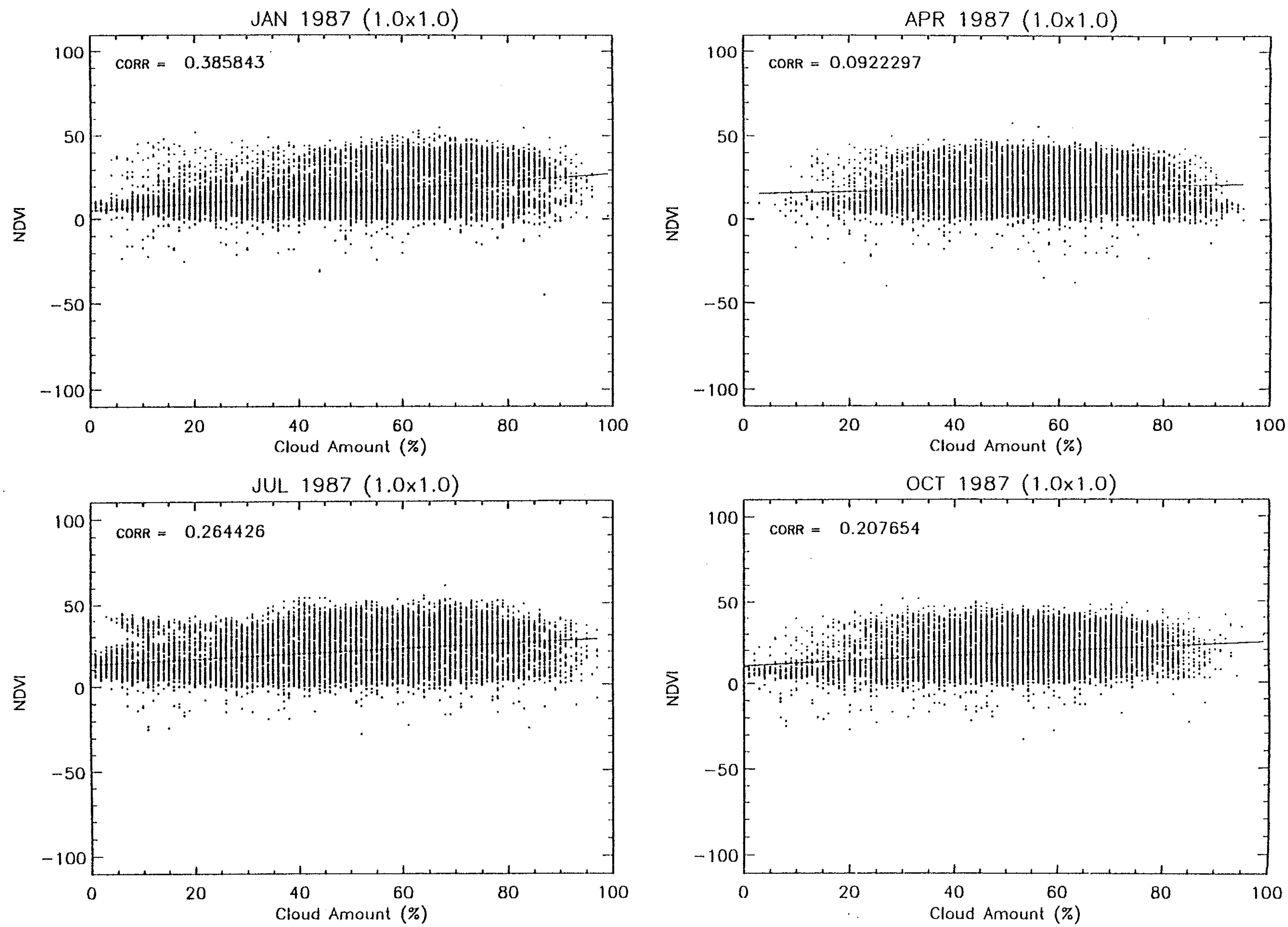


Fig. 1. Relationship between cloud amount and NDVI(x100) at 1.0°x1.0° grid box from -50°S to 50°N.

Development of a Nested Regional Model for the Conterminous U.S. and Formation of High Resolution Climate Change Scenarios with an Application to Crop-Climate Models

Linda O. Mearns and Filippo Giorgi; National Center for Atmospheric Research
William Easterling and Albert Weiss; University of Nebraska

Objectives: The overall objective of our research is the development of a nested regional model for the U.S. and formation of high resolution climate change scenarios with applications to a series of crop models in the central Great Plains region. This work will lead to a greater understanding of possible changes in climate in the central Great Plains and to better understanding of resulting impacts on crops. In the second year we proposed to further improve RegCM2 to overcome biases found in runs produced the first year, produce and analyze a multi-year run using European Center for Medium Range Weather Forecasting (ECMWF) boundary conditions, evaluate several general circulation models as candidates for providing boundary conditions for a control and doubled run of the regional model, and continue crop model testing with observed climate data at Nebraska and NCAR. The objective of the crop modeling procedures is to provide a method for determining whether higher spatial resolution climate change estimates than available from GCMs improve or otherwise cause substantial revision of the crop yield impacts simulated with GCM data.

Products: 1) Improved version of the NCAR RegCM, which will be made available to the scientific community. 2) High spatial and temporal resolution model output of all relevant climatic and surface variables over the U. S., centered on the Great Plains, for the ECMWF-driven validation run (and in year three for the control and doubled runs). 3) Testing of different types of crop models (e.g., EPIC, CERES) and scaling of simulated crop yield output at different spatial scales.

Approach: As described in the progress report at the end of year 1, a multi-year validation run revealed a number of model biases, such as a too dry lower boundary layer and excessive summer precipitation. The biases were so large that it was deemed necessary to reduce them before proceeding to the completion of climate simulations.

Model development aimed at the reduction of these biases thus became a major focus for the second year. The lower boundary layer dry bias was mostly caused by excessive vertical transport of moisture and subsequent detrainment from the boundary layer. We modified the vertical profiles of moisture diffusivity during daytime convection based on diffusivity profiles (by Wyngaard). The new diffusivity values are smaller than in the original model scheme in the lower boundary layer and significantly contributed to decreasing vertical moisture transport and reducing the local dry bias to acceptable values (less than a few tenth of g/kg).

Much work has been devoted to improving the simulation of summer precipitation. In order to better focus on the Central Plains region, reduce the computational requirements for the proposed experiments and speed up the completion of the project, the model domain was reduced (compared to the original experiments) to cover only the central and western U.S. rather than the whole continent. Two cases, summer of 1988 and summer of 1993 were chosen to test the model simulation of summer precipitation, since they are representative of a dry and a wet regime over the Central Plains. Boundary conditions were provided by ECMWF analyses of observations. We tested different model precipitation parameterizations and performed several adjustments on the setting of key parameters.

A model configuration was found which showed a reasonably good performance in simulating various characteristics of surface climatology over the region during these two extreme periods, with total simulated precipitation being close to observed in May, June, July (MJJ) 1988 and lower than observed by about 25 in MJJ 1993. The simulated surface hydrologic budgets and different precipitation statistics over the Upper Mississippi Basin were also analyzed in the paper, along with the model sensitivity to soil water content. This model configuration was then tested in a 2-year long simulation (fall 1986 through summer 1988) to verify the model simulation of seasonal climatology.

Results to Date: This 2-year run was recently completed, and we have preliminarily evaluated the climatology for both years (fall 86 -- summer 87 and fall 87 -- summer 88). The model performs best (when comparing mean seasonal temperature and precipitation with observations) in fall and winter (see example for fall on Figure 1). In spring, the pattern of precipitation over the central Plains is fairly well reproduced, although there is too much precipitation in the northwestern segment of the domain. Summer is still the season most difficult to simulate. The model produces too much precipitation over the Great Plains and model temperatures are too warm by about 2°C.

The other main research accomplishment at NCAR was evaluation of candidate general circulation models (GCMs) for the nested model runs over the Central Plains. Three GCMs are currently available for the nested model runs proposed in the present project: the NCAR GENESIS GCM (version 2.0), the Washington-Meehl version of the Community Climate Model (CCM) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) GCM. Output from present day and 2xCO experiments with these AGCMs coupled with mixed layer ocean models is available and has been analyzed to evaluate the model performances over the continental U.S. Based on temperature and precipitation criteria, the CSIRO model appears to perform the best over North America, although its 850 mb wind field appears a bit weak over the central U.S. From these preliminary evaluations we have tentatively chosen the CSIRO model to provide boundary conditions for the nesting experiment.

Crop Modeling Work at NCAR and Nebraska.

At NCAR two CERES crop models (soybean and winter wheat) have been set up for multi-year runs; and testing of the models at locations in Eastern Kansas and Iowa has begun.

At Nebraska procedures were developed to examine the agreement between observed and modeled estimates of crop productivity at different levels of spatial aggregation of climate and soils data. The procedures were tested on two pilot grid cells in the Great Plains study area: eastern and western Iowa. The procedures were developed with observed climate data in preparation for their application to the testing of climate scenarios developed with the RegCM for the central Great Plains. The observed climate record (1984-1992) has been constructed for two test grid cells, whose size corresponds to a typical GCM high horizontal resolution (2.8 Lat. and Long.), superimposed on Iowa (Figure 2). The GCM-size grid cells were subdivided into 9 and then 36 sub-grid cells. EPIC model farms and cooperative observing station climate data were organized for each of the three levels of aggregation (GCM, 9 sub-grid, 36 sub-grid scales). Observed county-level annual crop yield data (1984-1992) were aggregated to those three levels for comparison with crop model simulations.

Tests were performed to examine the agreement between simulated crop yields and observed yields over the three levels of spatial aggregation. The tests involved manipulation of only the climate and soils data. In one set of manipulations, climate data first were left aggregated at the GCM scale in the form of areal averages (referred to in tabular results below as "spatially uniform") and then climate data were disaggregated to each of the two subgrid scales (9, 36, referred to in tabular results as "spatially differentiated"). Soils were handled in the same manner as the climate data, with the most abundant soil-type representing the spatially uniform class for any given grid cell. All combinations of climate and soil aggregations were examined. In all cases, tests involved measuring the agreement between modeled crop yields and observed yields at different levels of aggregation, with the test statistic being the r^2. The initial crop tested was dryland maize.

In the eastern Iowa grid cell, the greatest agreement between modeled and observed yields (r^2=0.67) occurred when climate data were disaggregated to 36 subgrid cells, but using only a single soil type for the entire GCM grid cell. In western Iowa, the greatest agreement (r^2=0.80) occurred when both climate and soils data were disaggregated to 36 subgrid cells. The least agreement between modeled and observed yields occurred when climate and soils data were aggregated at the GCM scale. Though the best agreement between modeled and observed yields occurred at the finest grid resolution (36 subgrid cells) of climate data, the greatest improvement in agreement came in the initial disaggregation of climate data from the GCM grid cell to the 9 subgrid cells. Further disaggregation of climate data from 9 to 36 subgrid cells yielded only marginal improvement in agreement between modeled and observed yields. In virtually all cases, added spatial detail of soil types does little to improve agreement between modeled and observed yields.

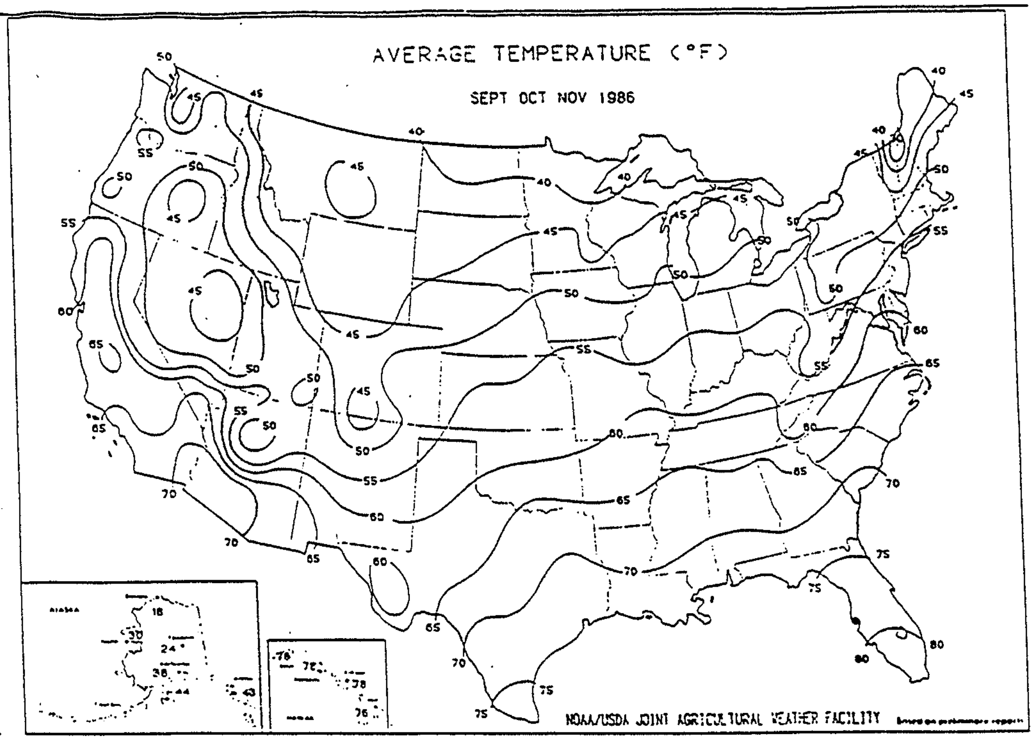
Manuscripts in preparation and submitted:

Giorgi, F., L. Mearns, C. Shields, and L. Mayer. A Regional Model Study of the Importance of Local versus Remote Controls of the 1988 Drought and the 1993 Flood over the central United States, submitted to J. Climate.

Presentations:

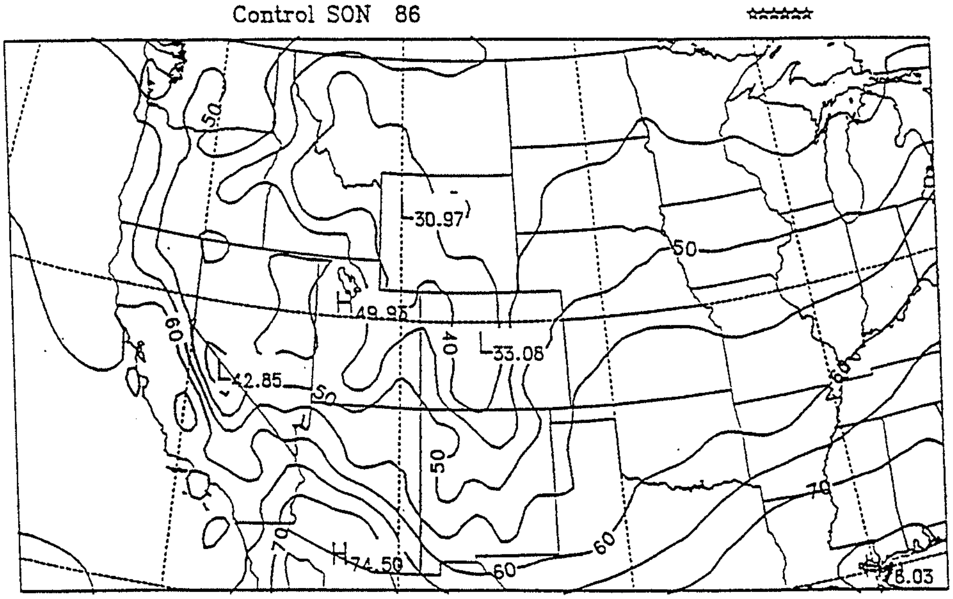
Mearns, L.O., F. Giorgi, and C. Shields. RegCM Model Results over the Great Plains, NIGEC PI's Meeting, Lincoln, Nebraska, Sept. 24, 1994.

Easterling, W.E., C.J. Hays, L.O. Mearns, etc. Human Dimensions of Global Change Meeting, Duke, North Carolina, June 1995.



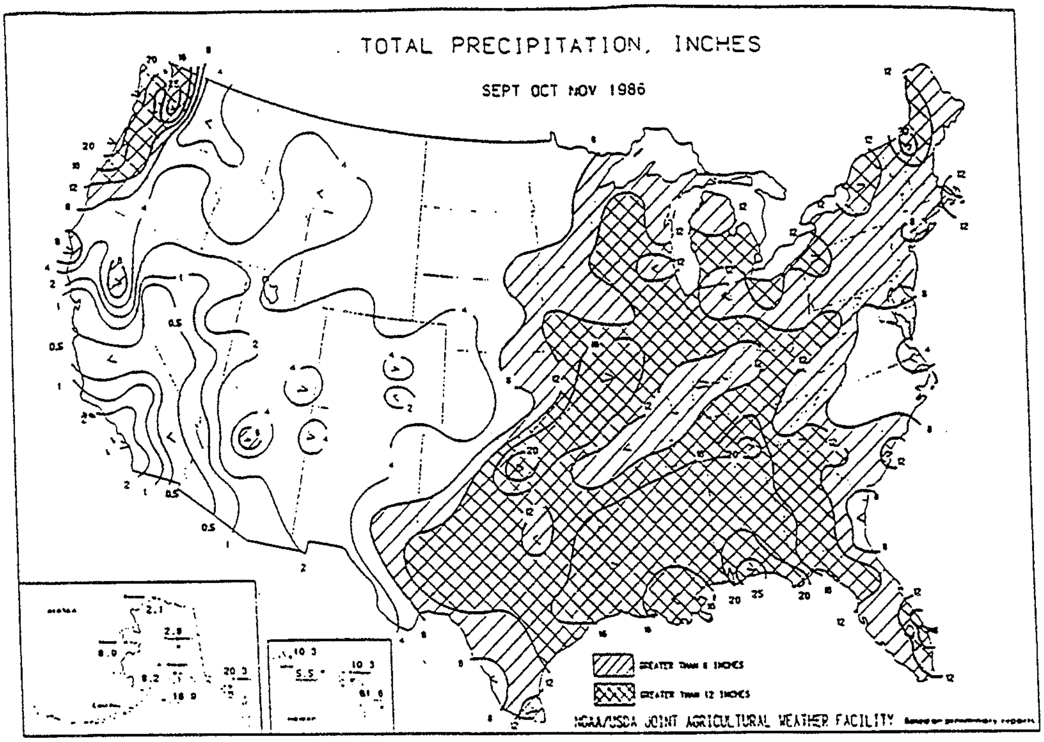
a.

Control SON 86



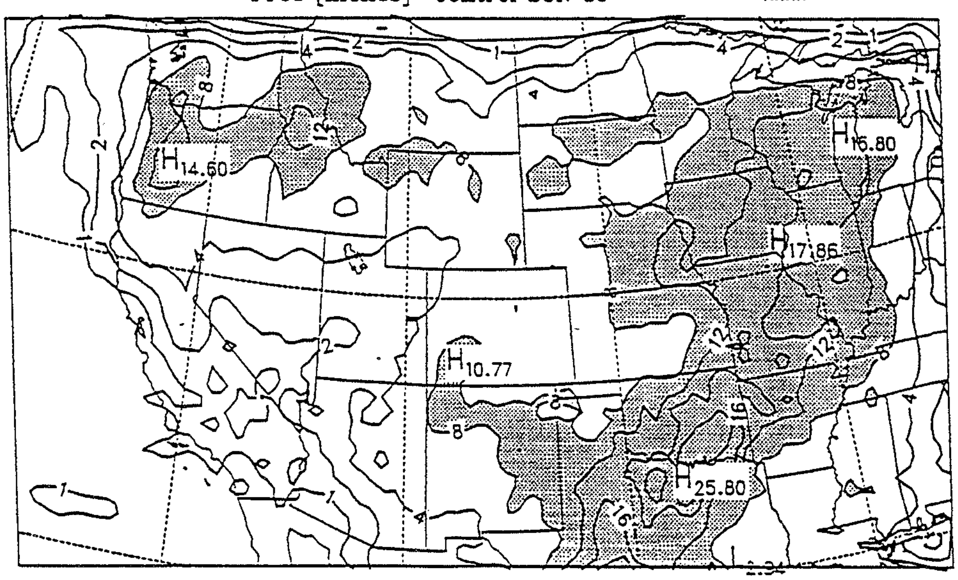
b.

1. Fall (September, October, November) 1986 observed (a.) and modeled (b.) mean temperature (°F); and observed (c.) and modeled (d.) total precipitation (total inches). For precipitation, contours above 8 inches are shaded. Observations are from the issue of *Weekly Weather and Crop Bulletin*, Dec. 23, 1986.



c.

Prec [inches] Control SON 86

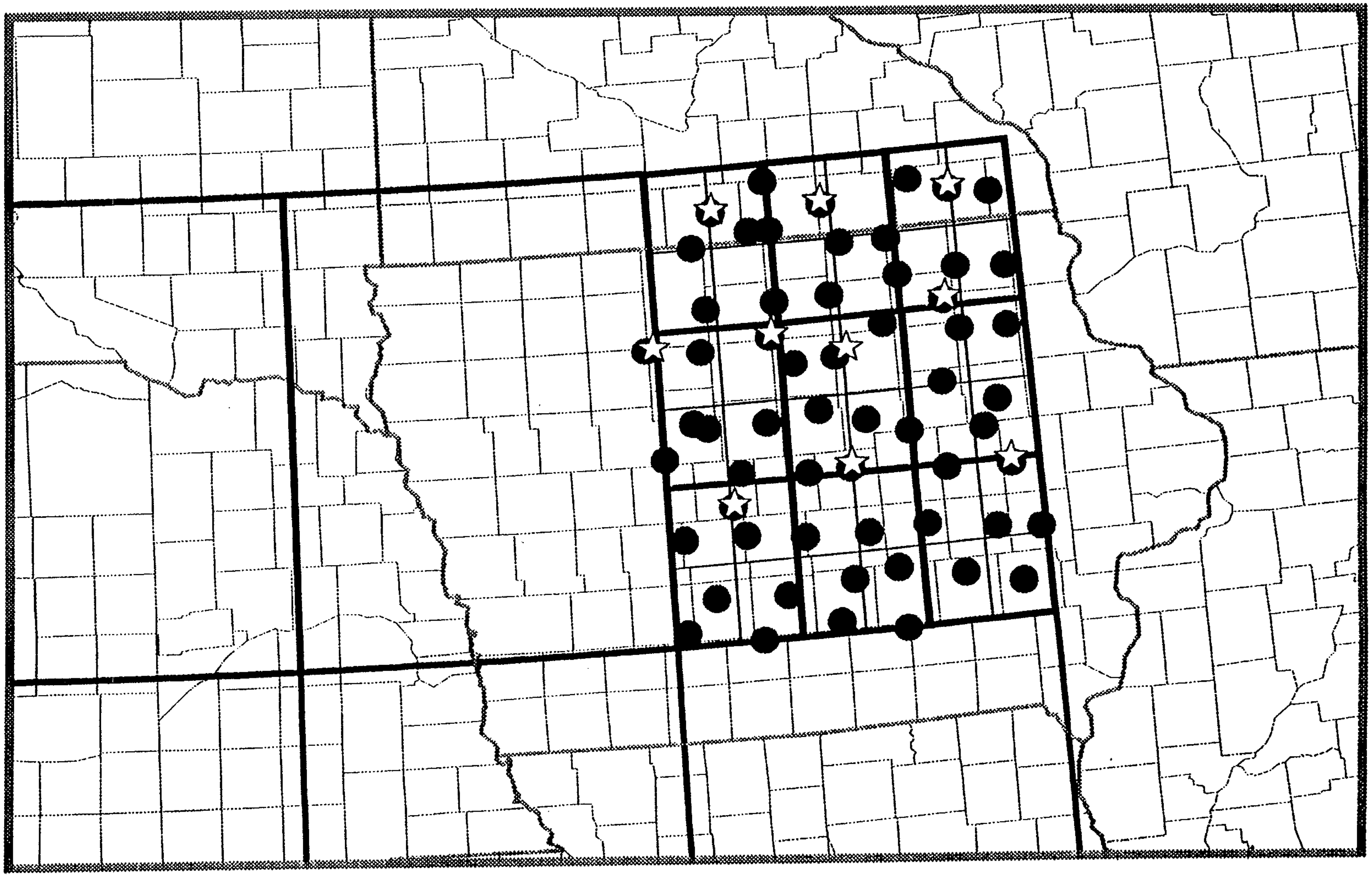


d.

Figure 1 (continued)

Figure 2

Scale Resolution



☆ Locations of weather stations used in EPIC's weather generator

● Locations of cooperative weather stations

The Detection of Climate Change Using Long Term Daily Climate Records Over Grassland Regions of the Northern Hemisphere

Michael A. Palecki and Kenneth F. Dewey; University of Nebraska-Lincoln
David A. Robinson; Rutgers University
Daniel J. Leathers; University of Delaware

Objectives: The primary objective of this research project is the synthesis of a new type of climate change scenario, based on a minimal use of GCM guidance and a reliance on long term records of daily observations of the seasonal cycle to provide suitable climate analogs. The "calendar shift" method, as it has been named, will be utilized in the coming year to provide a variety of climate scenarios for studies of the sensitivity of the soil water budgets of the Great Plains to potential future climate states.

Secondary goals in support of the primary objective include the preparation and quality control of long times series of daily observations; the climatological analysis of seasonal cycle relationships among temperature, precipitation, snowfall and snow cover, clouds, and dew point; the generation of historical water budgets for the Great Plains region; and the examination of climate change in the Great Plains at sub-monthly temporal resolution. All of these activities are necessary to increase the understanding of the observational data being used for climate change scenario production, correct scenarios for climatological incongruities caused by calendar shifting hydrologic variables (such as snow cover) that are affected by radiation, and complete thrusts that were initiated in the first year, prior to the establishment of the present primary objective.

Products: The calendar shift methodology for generating climate change scenarios is the primary product of this project year. The generation and analysis of several different climate scenarios (based on differing GCM guidance) for the Great Plains will be completed in late summer. During the next year, the water budget characteristics of these scenarios will be calculated to assess the range of possible climate change impacts represented by the scenarios.

Project outputs nearing completion or already completed include: 1) quality controlled daily climate records extending for over one hundred years in the Great Plains; 2) identification of the physical processes responsible for regional differences and asymmetries in daily resolution temperature seasonal cycles; 3) analysis of mechanisms responsible for coherent climate change signals of less than one month duration within the seasonal cycle; and 4) development of a climate change detection method based on seasonal fingerprint characteristics.

Approach: The basic idea of the calendar shift method of generating climate change scenarios is to use the seasonal cycle itself to provide analogs for future states. In the Great Plains, the amplitude of the seasonal cycle is large enough that a simple reassignment of daily observations to a new set of calendar days shifted towards winter can provide scenarios for all days but the central period of summer. A scenario created in this manner has the advantage of possessing dynamically consistent relationships between variables and climate processes, as any day of the scenario consists of observations taken on a single day throughout the Great Plains.

Monthly GCM temperature output for a region provides the temporal guidance for the calendar shift. Large scale temperature is one of the more reliable products of GCMs, as most models are tuned to deliver accurate surface temperature conditions in control runs. No GCM precipitation fields are used in this approach. In addition to equilibrium $2xCO_2$ - $1xCO_2$ model change projections, scenarios for three periods during a transient run by the GFDL GCM are also being produced.

While the calendar shift method is based on a simple idea, there are quite a few complexities that must be overcome. Methods for repairing discontinuities where adjacent shifted months overlap or gap, adjusting snow cover for the radiation input differences when shifting within the season, and filling the summer gap induced by shifting days toward winter have all been addressed. The summer temperature gap is filled with daily data that are not calendar shifted, but are instead temperature shifted by the magnitude of the GCM $2xCO_2$ - $1xCO_2$ model projection differences. An additional temperature shift is made to the early and late summer periods near the summer gap, in order to remove a step change at the transition. No adjustment is made to precipitation amounts or variability, as there are considerable disagreements regarding Great Plains precipitation projections between various GCMs.

The impact of various climate scenarios on hydrologic parameters in the Great Plains will be assessed in the coming year using the Thornthwaite-Mather climatic water budget methodology. A simple approach is made necessary by the present limitation of the scenario generation to temperature and precipitation variables. However, this water budget approach has been demonstrated to be quite robust for a great variety of circumstances. Inputs also include date and latitude for solar calculations; the dates will be set by the calendar shift, thus explicitly making a radiation adjustment to the water budget calculations. The water budget values for the last 100 years have also been calculated for comparative purposes.

Methodologies for the secondary goals consist of univariate and multivariate statistical analyses. Our focus on daily resolution data from long observational time series provides us with a unique perspective that is allowing us to address some fundamental aspects of climate processes. Climatological relationships between daily resolution seasonal cycles of temperature across space have been identified with regression and principal component analysis. The identification of trend annual cycles, constructed from the trends of individual day temperature time series, is another unique method developed for this project. This has been utilized both for climate change detection and the assessment of climate change processes.

Results-to-Date: In this section, the discussion is confined to results from Year 2. The main objective of Year 2 has been achieved: the development of the calendar shift methodology for climate change scenario generation. A calendar shifted scenario for Gothenberg, Nebraska is shown in Figure 1. The $2xCO_2$ - $1xCO_2$ temperature change in the central and northern Great Plains in the Canadian Climate Center (CCC) GCM were spatially averaged for every month. The differences between the model runs range from 3.71°C in November to 9.06°C in February. Setting the nadir of winter at January 14, each half of the year is calendar shifted, so that warmer, more summer-like days are taken to represent dates closer to winter. Because of the enormous warming generated in the CCC model, the period from June 22 to August 22 does not have a seasonal analog. This is a worse case; the gap is narrower in scenarios utilizing a GFDL GCM simulation of transiently increasing CO_2 levels. The gap period, as mentioned above, is shifted to warmer temperatures without any change in the representative calendar day.

The second part of Figure 1 shows a comparison between the CCC GCM $2xCO_2$ output for a grid point near Gothenberg with the calendar shifted change scenario. The agreement is substantial, except for the spring, where the model starts out with temperatures in its control run that are colder than observed. The calendar shifted scenario, while representing a temperature change similar to model, provides tremendous advantages. First, all the scenarios produced in this study have 50 year or more of data, including all the natural variability of the real climate system. Second, the same calendar dates can be used to provide scenarios of other variables such as precipitation. Finally, all the scenario variables will be dynamically consistent, having been drawn from the same real daily observation set.

In preparation for the impact analysis, a 100-year climatology of water budget variables for the Great Plains region of the United States has been completed. This new data base will allow us to better understand changes in hydrologic parameters such as soil moisture under temperature and precipitation regimes generated by our calendar shift methodology. Figure 2 shows the average growing season (April through September) soil moisture deficit across the Great Plains region for the period 1895 through 1994. As is well known, the plains region lacks sufficient water input during these months for the growth of several crop species without the benefit of irrigation. However, the variability around this mean is quite large, and is captured by this data set. During the growing season of 1936, for example, deficit values across the plains region were greater than 10 inches over the entire area. Alternately, during the growing season of 1993, much of the plains region experienced no soil moisture deficit. Instead, surpluses of soil moisture of over 10 inches were found across eastern sections of the region. This data base will be invaluable for comparisons with our water budget scenarios.

Our examination of the annual cycle of the daily temperature range and the mechanisms that control it is nearing completion. Our work has shown that there are distinct regional differences in the annual cycle of the daily temperature range across the coterminous United States. These annual cycle differences are attributed to two major synoptic controls: the annual cycles of both dew point temperature and cloud cover. For example, across the northern High Plains of the United States the daily temperature range is strongly associated with the annual cycle of cloud cover. The average annual cycles of both variables at Billings shows that the peak in daily temperature range in August is simultaneous with a minimum in the average daily cloud cover (Figure 3). However, the cloud cover/temperature range relationship does not hold for other sections of the Great Plains. In many of these areas, the annual cycle of the dew point temperature is strongly associated with the daily temperature range.

The assembly of a snow data base for further comparative analysis with other variables has been completed. This set includes daily reports of snow cover and snowfall from either first-order or cooperative stations located near the sites where we have full dew point and cloud coverage data. These data are from the Historical Daily Climate Dataset (HDCD) developed by Robinson, and have already been subject to a first-order quality control. A more detailed assessment of data from candidate stations will also be undertaken in the final selection process. As a result, the stations ultimately selected should have few if any instances of missing or questionable data. Mean daily climatologies are being created for such conditions as days with greater than or equal to 1", 3", 6".... of snow cover, and for days exceeding certain snowfall thresholds. These data will also be utilized in creating snow adjustments for climate change scenarios to account for the effects of radiation input changes due to calendar shifts.

Many other results are in the process of final analysis and/or paper preparation, and were discussed in the Year 1 progress report. Please refer to this document for further information.

Presentations:

Robinson, D.A., D.J. Leathers, M.A. Palecki, and K.F. Dewey 1993: Climate variability as seen in daily temperature structure. MINIMAX Workshop, College Park, MD, September 27-30, 1993. Sponsored jointly by the National Oceanic and Atmospheric Administration National Environmental Watch Program and the Department of Energy Global Change Research Program.

Palecki, M.A., 1994a: The Onset of Spring in the Eastern United States During the 20th Century. Sixth Conference on Climate Variations, American Meteorological Society, Nashville, TN, January 23-28, 1994.

Palecki, M.A.: Detection of climate change through the use of daily resolution observations. Nineteenth Climate Diagnostics Workshop, College Park, MD, November 14-18, 1994.

Climate Variability and Change in the Instrumental Record: Daily Time Periods, Annual Meeting of the Association of American Geographers, San Francisco, CA, March 29 - April 2, 1994. (A conference special session organized by M.A. Palecki):
Robinson, D.A., 1994: Issues concerning the quality of daily climatic data.
Dewey, K.F., 1994: Spatial and temporal singularities in a long-term daily max/min temperature series.
Palecki, M.A., 1994b: Sub-monthly scale climate dynamics.

Proceedings:

Robinson, D.A., D.J. Leathers, M.A. Palecki, and K.F. Dewey 1993: Climate variability as seen in daily temperature structure. Pages 201-230 in: Asymmetric Change of Daily Temperature Range - Proceedings of the International MINIMAX Workshop, College Park, MD, September 27-30, 1993. Department of Energy.

Palecki, M.A., 1994: The Onset of Spring in the Eastern United States During the 20th Century. Pages 108-109 in: Pre-Print Volume, Sixth Conference on Climate Variations, American Meteorological Society, Nashville, TN, January 23-28, 1994.

Palecki, M.A.: Detection of climate change through the use of daily resolution observations. Pages 277-280 in: Proceedings of the Nineteenth Climate Diagnostics Workshop, College Park, MD, November 14-18, 1994.

Journal Article:

Robinson, D.A., D.J. Leathers, M.A. Palecki, and K.F. Dewey. Some observations on climate variability as seen in daily temperature structure. Atmospheric Research (in press).

Articles and Papers in Preparation:

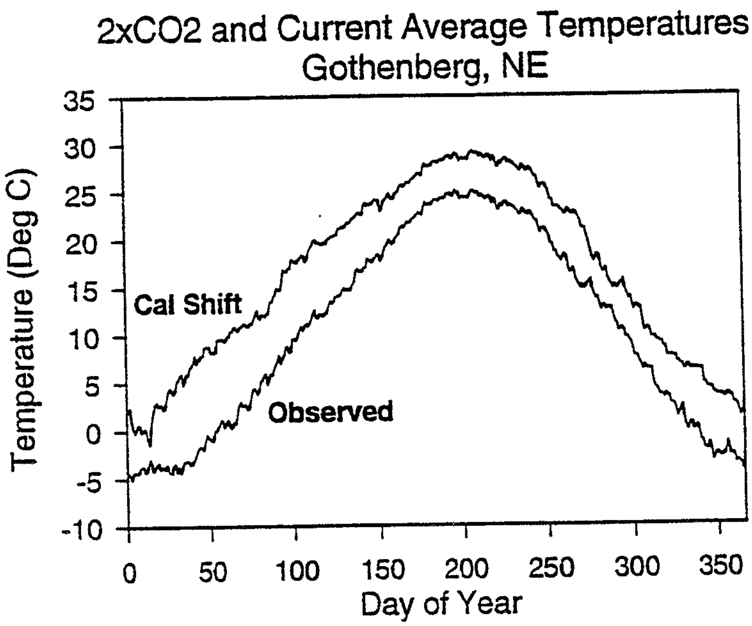
Leathers, D.J., D.A. Robinson, M.A. Palecki, and K.F. Dewey: The spatial structure and a synoptic climatology of the annual cycle of daily temperature range over the United States. To be submitted to International Journal of Climatology.

Dewey, K.F., M.A. Palecki, D.A. Robinson, and D.J. Leathers: A climatology of asymmetries and singularities in the annual cycles of max and min temperatures for the conterminous United States. To be submitted to International Journal of Climatology.

Palecki, M.A., K.F. Dewey, D.J. Leathers, and D.A. Robinson: Fine temporal structures in seasonal climate change. To be submitted to Journal of Climate.

Student Participation:

Natalie Williams 50%


2xCO2 and Current Average Temperatures
Gothenberg, NE
Temperature (Deg C)
35
30
25
20
15
10
5
0
-5
-10
Cal Shift
Observed
0
50
100
150
200
250
300
350
Day of Year

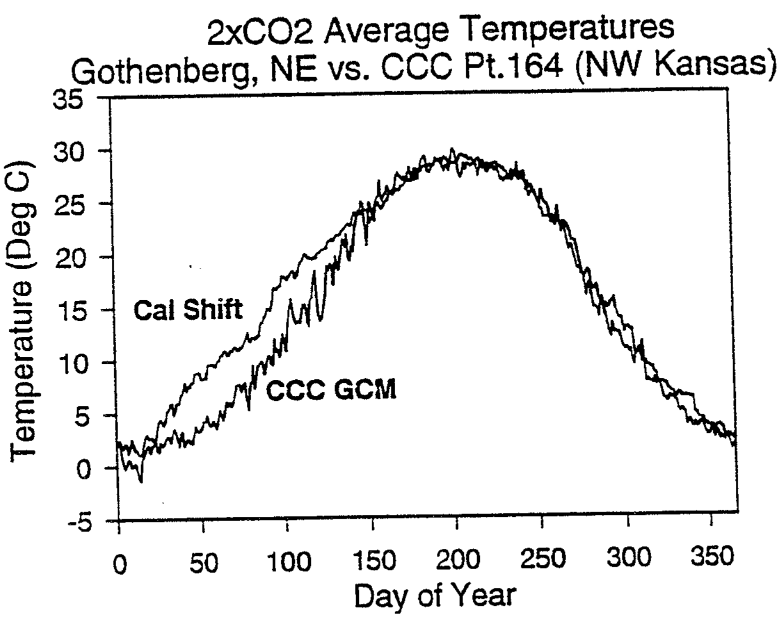

2xCO2 Average Temperatures
Gothenberg, NE vs. CCC Pt.164 (NW Kansas)
Temperature (Deg C)
35
30
25
20
15
10
5
0
-5
Cal Shift
CCC GCM
0
50
100
150
200
250
300
350
Day of Year

Figure 1

Average Growing Season Soil Moisture Deficit

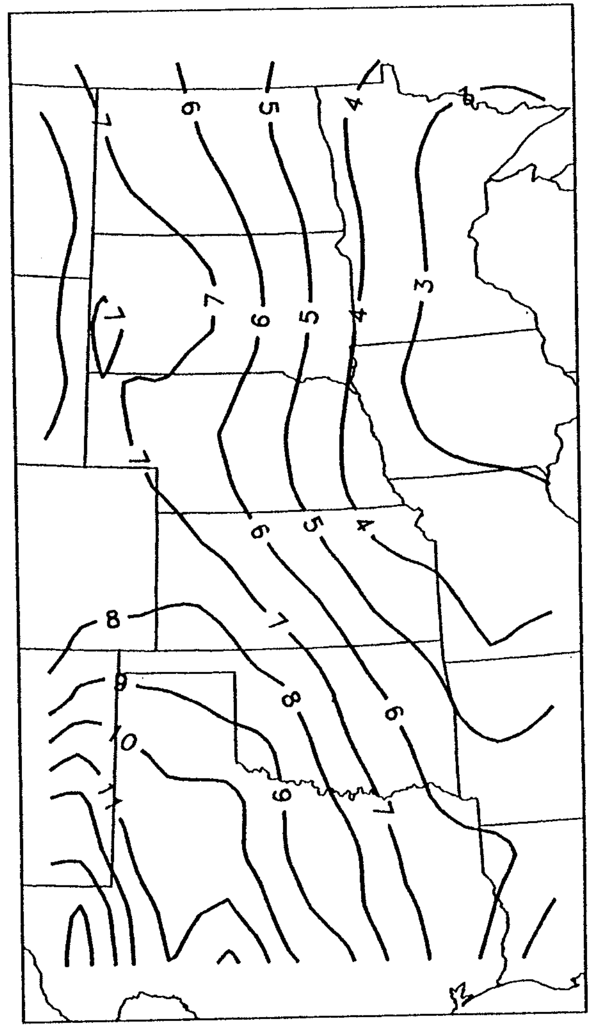


Figure 2

Billings, MT

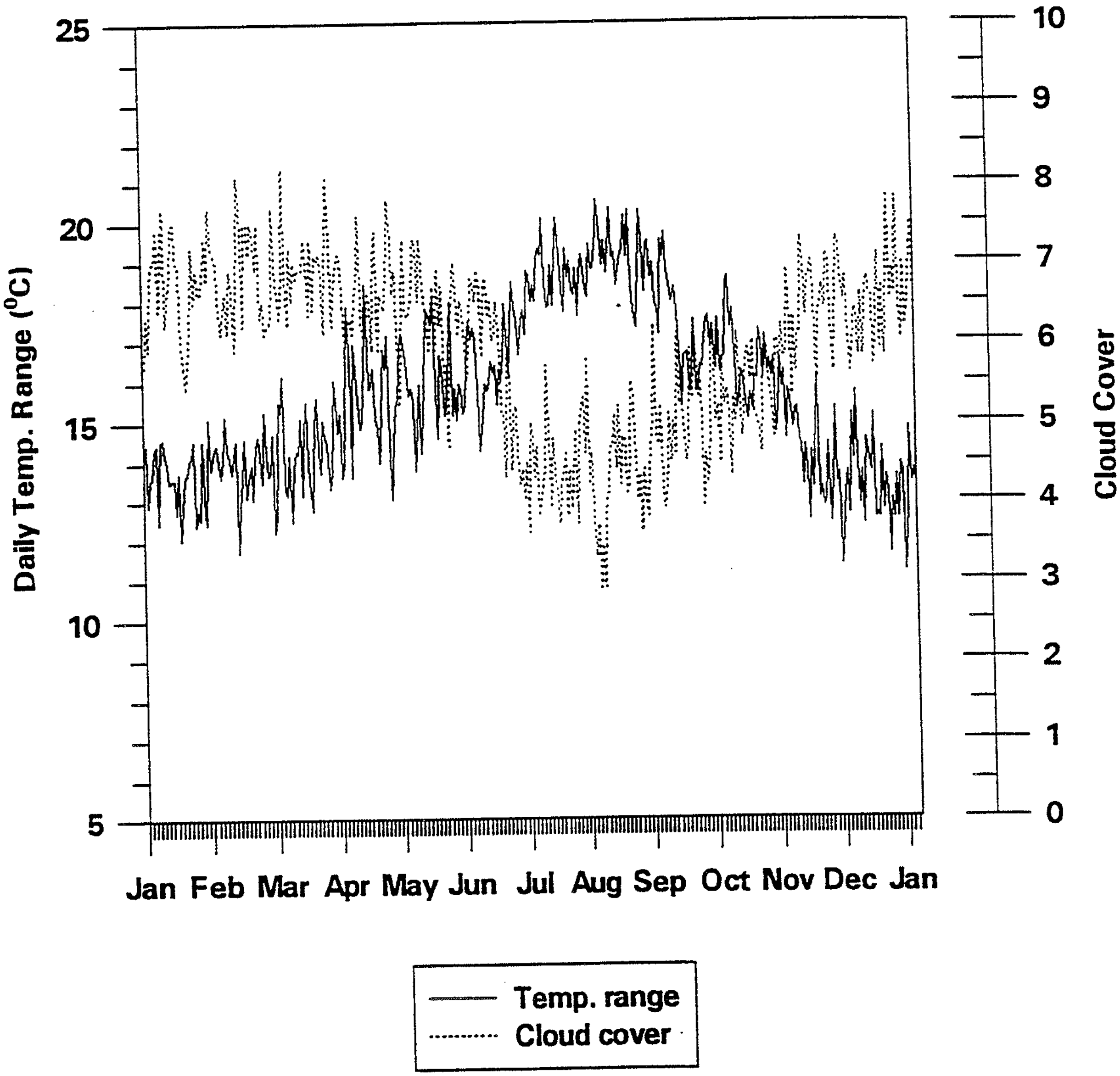


Figure 3

Assessment of Climate Change on a Mixed Agricultural Landscape on the North American Great Plains

J.R. Brandle, M.L. Marsh, W.E. Easterling and D.S. Guertin; University of Nebraska
E.S. Takle and H. Wang; Iowa State University
R.A. Schmidt, M.M. Schoenberger & R.L. Jairell; USDA-Forest Service
I.V. Litvina; Agrophysical Research Institute, Russia

Introduction: The Great Plains is a grassland ecosystem that has undergone large-scale conversion to agriculture. Linear forest systems (shelterbelts and riparian corridors) are the dominant forest ecosystem of the region and play important roles in the overall landscape. We postulate that these systems have an influence on the local microclimate far beyond their size and contribute significant ecological and economic values to the Great Plains agroecosystem.

Objectives: The goal of this project is to examine the potential impacts of climate change on the roles trees play in Great Plains ecosystems. This report will deal with three objectives addressed during the past year: 1) to estimate the effect of linear forests on wind flow and the resulting microclimate as the basis for estimating how climate change may alter this effect, 2) to estimate the effects of potential climate change on biological diversity in riparian forests in the Great Plains, and 3) to estimate the economic impact of existing shelterbelts on regional (ND, SD, NE, KS) economies.

Products: The products defined here represent those expected at the conclusion of the study. Intermediate products are discussed in the approach section and are described as they relate to individual steps within the entire scope of the project.

1. An understanding of the influence of a regional system of linear forests on wind flow and the resulting microclimate of crop fields.
2. An assessment of the ability of shelter to moderate the potential impacts of a changing climate on crop production in sheltered fields.
3. An individual-based model to predict tree species diversity in the Great Plains under conditions of climate change.
4. An avian species diversity model based on the habitat characteristics of linear forested strips found in the Great Plains.
5. An analysis of the economic impacts of linear forests found in the Great Plains under changing climate scenarios.

Approach and Results to Date:

<u>Wind flow responses:</u> A nonhydrostatic shelterbelt turbulent boundary-layer model was used to simulate the effects of various shelterbelt configurations and approach wind angles on horizontal and vertical profiles of wind speed.

Using the numerical model, we have examined the changes to the flow field in the lee of a shelterbelt when the wind is perpendicular to the belt. The model shows, and field studies confirm, that the location of maximum wind reduction moves toward the shelterbelt when the approach flow direction departs from normal, and that the wind speed in shelter may exceed the undisturbed wind speed in the region 3 to 15 H to the lee because of the channeling effect of the shelterbelt (see Figure 1).

The change in sheltering effect due to an oblique wind is partially a result of the increase of effective density due to the longer path through the belt for oblique flow. On the other hand, the shelter cannot reduce the wind component parallel to the shelter as efficiently as the component perpendicular to the belt. These two factors depend on incident angle and height.

Regional shelterbelt networks alter not only the atmospheric boundary-layer structure and surface drag force, but also the mesoscale regional radiation and energy partitions and the water balance. Comparative analysis in China has shown that regional mean wind speed was reduced by 20%, regional evaporation was reduced by 14%, and air temperature increased by 0.4°C in spring and decreased by 0.3°C in summer. Preliminary simulations of a regional network of shelterbelts with the ISU shelterbelt model showed that, although turbulence is increased within the shelter, near-surface turbulence intensity over the sheltered region is greatly diminished. It is this near-surface turbulence that affects the energy, mass, and water vapor transport, therefore the network causes a reduction in regional evaporation by reducing near-surface turbulence.

Biological diversity: Forest dynamics models are frequently used to predict the effects of climate or other environmental conditions on species composition and diversity of forests (see Figure 2). *SEEDSCAPE*, a forest dynamics model similar in structure to *JABOWA* and *FORET*, has been modified to represent Great Plains riparian forests by incorporating:

1. a spatially explicit landscape mosaic up to 1 km^2, instead of homogeneous forests;
2. plot-specific tree growth conditions based on local soil types within this landscape;
3. plot-specific initial vegetation types;
4. dispersal of seeds from seed-producing trees to plots throughout the landscape;
5. fluctuating water table in riparian zones (highest in spring, lowest in autumn);
6. increased light availability to plots at edges of forest corridors;
7. incorporation of commercially minor but ecologically important tree species of the Great Plains.

SEEDSCAPE is currently configured to model conditions found at the University of Nebraska Agricultural and Development Center (ARDC) near Mead, Nebraska where the model is being developed. Climate data are from a riparian site at ARDC. Climate change is currently modeled as a 3°C increase in temperature and a 30% decrease in precipitation. Regional climate change scenarios from Mearns et al. (this report) will eventually be used in *SEEDSCAPE*.

The construction of the model is complete. *SEEDSCAPE* has undergone initial testing, and the model output is consistent with vegetation sampled in a riparian forest corridor at ARDC. Currently, modeled effects of climate change on vegetation are still preliminary until *SEEDSCAPE* is more thoroughly validated. Validation of the model simulation is to be completed by the end of summer 1995 after comparisons with historical vegetation records at ARDC and elsewhere in Nebraska.

Regional economics:

We are examining shelterbelts within the broader agricultural production system and attempting to integrate their numerous economic benefits using a systems approach. This entails assimilating market and non-market benefits such as increased productivity, erosion control, ecological enhancement, climate change buffering capacities, recreational opportunities, and aesthetic enhancement.

Efforts to this point have focused on measurement of crop productivity benefits in a four state region including: ND, SD, NE and KS. *ImPlan* (an input/output model developed by the USDA-Forest Service) has been utilized in determining the order of magnitude of the Great Plains regional economic benefit of existing shelterbelt systems.

Three different impact scenarios were modeled for seven major crops: corn, wheat, soybeans, sunflower, sorghum, oats and barley. Crop yield responses were based on previously published yield studies. Results are an estimate of the magnitude of the response of the economy to shelterbelt technology.

In the first scenario, a final gross benefit to the regional economy was measured. Shelterbelts were found to provide an additional $253 million to gross regional product. Total industrial output and employee compensation benefits were positively impacted by $337 and $46 million respectively. Jobs provided by the benefits of shelter total 3952 and population is 6422 persons greater than would otherwise be the case.

The second scenario measures the opportunity cost of leaving land in shelter versus cropping those acres. Results show a cost to the regional economy of $17 million in gross regional product, $22 and $3 million in total industrial output and employee compensation benefits, a net job loss of 393 and a population which is smaller by 242.

The third scenario examines the final benefits of optimally sized shelterbelts (i.e., no wasted acreage on excess shelterbelt widths) which was simulated by increasing total production in the appropriate commodity sectors. In this scenario, the opportunity cost of production foregone on acres occupied by shelterbelts is less than was found in scenario two. An appropriately designed system of shelterbelts was found to increase gross regional product by $53 million. Total industrial output and employee compensation benefits are $69 and $10 million higher. Jobs provided total 823 while the population is 1338 persons greater. Therefore it appears that the impact on the regional economy of a system of shelterbelts is dependent upon appropriate design.

Student participation: Mr. Mark Marsh is a Ph.D. student in Economics at UNL and is working on the economic assessment (50%). Mr. Chien-jung Yu is a Ph.D. student in Aerospace Engineering at ISU and is working on the numerical model of Litvina (50%).

Manuscripts in preparation or submitted:

Easterling, W.E., C.J. Hays, M.M. Easterling, and J.R. Brandle. The Role of Trees in the Adaptation of Great Plains Agroecosystems to Climatic Change: A Sensitivity Analysis of Shelterbelts. For resubmission to Agriculture, Ecosystems and Environment, September 1995.

Guertin, D.S., W.E. Easterling, and J.R. Brandle. Global change and biological diversity in the Great Plains: a review of methods and assessment of prospects. For submission to Conservation Biology, August 1995.

Wang, H., and E.S. Takle. On shelter efficiency of shelterbelts in oblique winds. Provisionally accepted by Agriculture and Forest Meteorology.

Wang, H., and E.S. Takle. On the relationship between drag and pressure coefficients for a shelterbelt imbedded in the turbulent atmospheric boundary layer. For submission to Boundary Layer Meteorology.

Wang, H. and E.S. Takle. Momentum budget of boundary-layer flow perturbed by a shelterbelt. For submission to Boundary Layer Meteorology. Jointly supported by NIGEC and USDA/CSRS NRI Competitive Grant #93371018954.

Presentations:

Alkhalil, A., I.V. Litvina, R.A. Schmidt, J.R. Brandle, and E.S. Takle. Determination of shelterbelt porosity parameters from measurements and a model. American Meteorological Society, Charlotte, NC.

Brandle, J.R. and M.L. Marsh. Regional economic impacts of field windbreaks: A comparison of single-row and multiple-row systems. Association for Temperate Agroforestry, Boise, ID.

Guertin, D. Using simulation models to estimate ecological effects of climate change in Great Plains woodlands. Department of Agricultural Meteorology seminar, University of Nebraska, Lincoln.

Guertin, D., W.E. Easterling, and J.R. Brandle. Using simulation modeling to estimate effects of climate change on Great Plains Woodlands. Ecological Society of America, Snowbird, UT.

Marsh, M.L., J.R. Brandle, L. Hodges, G.F. Hayden, R.F. Riefler, B.B. Johnson, W.E. Easterling. Regional economic impacts of a system of field shelterbelts in Nebraska. American Society of Agronomy, St. Louis, MO.

Schmidt, R.A., R.L. Jairell, J.R. Brandle, E.S. Takle, and I.V Litvina. Windbreak shelter as a function of wind direction. American Meteorological Society, Charlotte, NC.

Wang, H., and E.S. Takle. Simulations of mean and turbulent properties of oblique flows near agricultural shelterbelts. American Meteorological Society, Charlotte, NC.

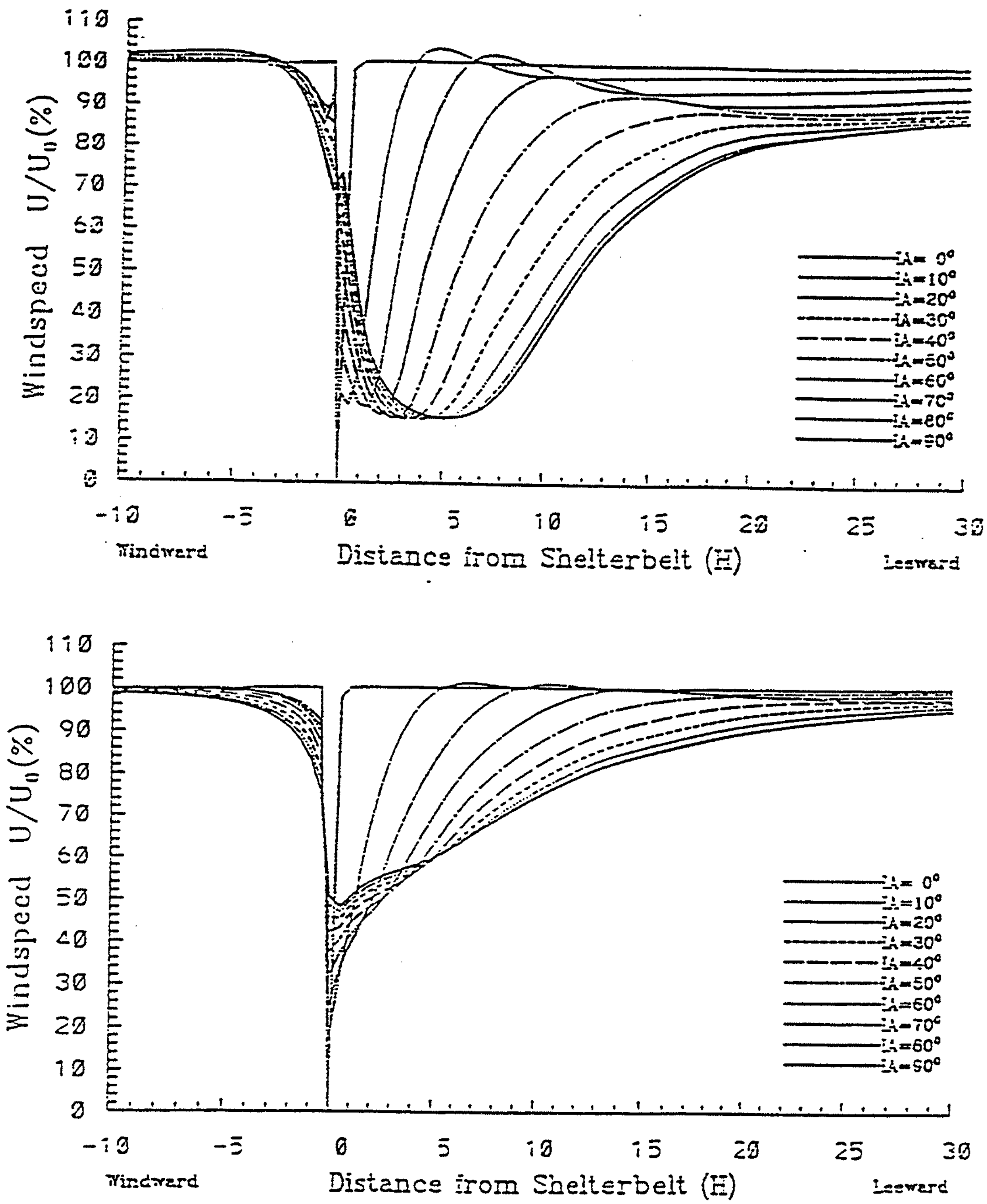


Figure 1. Horizontal profiles of normalized wind speed for various approach-wind incidence angles (IA), porosity of 50%, width of 0.5H, a) height of 0.1H, b) height of 0.7H.

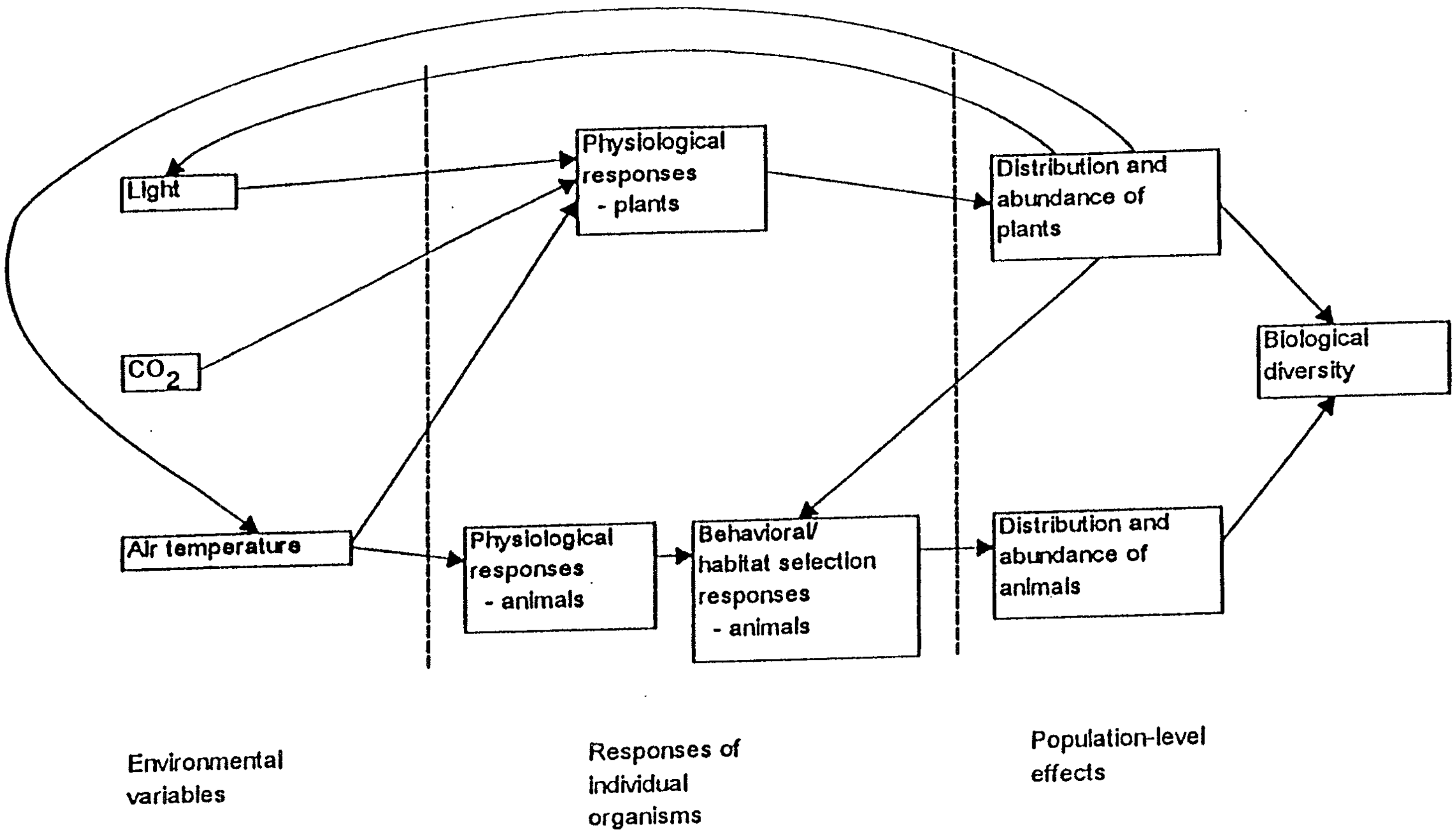


Figure 2. Structure of individual-based models to estimate change on populations of plants (top) and animals (bottom).

The Economic and Environmental Impact of Major Shifts in Land Use into Energy Biomass Production for Part of the Great Plains

Paul Dyke, Raghavan Srinivasan and Ranjan Muttiah; Texas A&M University System
Norman Rosenberg, Robert Brown and Daniel Epstein; Pacific Northwest Laboratories/Battelle
William Easterling and Cynthia Hays; University of Nebraska

Objective: A recognized need exist for alternatives to fossil fuel sources of energy which will reduce dependence on foreign oil, reduce emissions of CO_2 and provide an economically feasible and environmentally sound renewable energy source. One promising option is the use of biomass for energy production. Meeting this need could serve three important objectives of U.S. energy policy simultaneously: promoting the transition from nonrenewable to renewable sources of energy, mitigating the greenhouse effect, and assisting farmers in some agricultural regions in adapting to climate change.

This study addresses five questions: 1) Can woody and herbaceous biomass compete economically with traditional agriculture at the firm or farm level for the use of land and water resources under the existing climate? 2) What are the environmental impacts of large scale biomass production compared with those of traditional agricultural production? 3) How might CO_2 induced climate change affect the assessment of the economic and environmental feasibility of biomass since the process of substituting biomass for fossil fuels would occur gradually over several decades? 4) What would the impacts be of large scale biomass production on the regional economy as a whole, and how would these effects compare with those of continued conventional agricultural uses of the region's land and water resources? 5) How might public perceptions of the environmental and health consequences affect achievement of the conversion to large scale biomass production both without and with climate change.

Product: The work proposed here will provide vital information to the determination of the impacts of climate change on the net systems of importance to human activity in the Great Plains. The potential for using large land area to produce biomass for energy is an issue which needs additional research. This study will quantify potential environmental and economic impacts. Environmental simulation and economic models can provide insight and improved understanding of alternative technology and policy for adapting to and mitigating possible future climate change.

Approach: The study has four principal parts: 1) An analysis of the economic and environmental characteristics of biomass production at the farm level relative to those of conventional agricultural practices in the region; 2) An analysis of the comparative economic and environmental characteristics when biomass production is expanded to the regional scale; 3) Analysis of the comparative regional scale impacts on the MINK (Missouri - Iowa - Nebraska - Kansas) economy as a whole; 4) An analysis of the difference climate change would make to the results of parts 1, 2, and 3.

The farm level analysis (part 1) is using the EPIC biophysical process model. The data sets developed for the MINK study (initially 30 farms) are being used as the base data for the case of conventional agricultural and biomass production. The regional analysis (part 2) is using the MINK watersheds from HUMUS (Hydrologic Model of the U.S.) to provide accounting of the regional impacts on the environment. The economic impacts (part 3) will use the ASM (Agricultural Sector Model) to address the regional economic impacts changes to biomass production. (This analysis will be done in years two and three of the study.) The Nested Regional GCM model will provide climate change data to study energy biomass production impacts under alternative climatic change scenarios (part 4).

Activities in year one (FY 94) have concentrated on part 1). In year two (FY95) we will address parts 2), and 3). In year three (FY 96) we will address the climatic impacts of part 4).

The EPIC model has been used to simulate both traditional crops and biomass energy crops on the scale of a farm field. The 'representative farm' approach, outlined in the MINK study, was used to model both crops and biomass. The climate is being simulated using two (2) scenarios. Historical normal climate and 1930's dustbowl climate. At a later date the dustbowl scenario will be replaced with climate change information from the GCM model. Data sets for thirty representative farms were spread across the four state area. The traditional crops scenario is being represented by rotations of corn, soybeans, sorghum, and wheat in various combinations depending on the practices found in the area.

For the biomass crop, switchgrass (*panicum virgatum* L.) was chosen for growth simulations on the same representative farms using the same climate and soils as was used in the traditional scenario.

To study the regional impacts of shifting land use from traditional crops to biomass energy crops on water use, water quality, runoff, erosion and other environmental indicators, the HUMUS model is being used for the watersheds of the four state region. To study the potential impacts of marginal increments of land use changes into biomass production, five scenarios are being set up to reflect the various levels of conversion. These scenarios will step from 0% to 80% of the cropland acres in biomass production in increments of 20%. Both EPIC and HUMUS allow the simulation of irrigation management on production acreage. Biomass production may impact the quantities of water in the watershed available for use on irrigated acreage as well as determining the impacts of increasing or decreasing irrigation on stream flows.

Results to Date: As of this report, the basic data sets for EPIC have been assembled and preliminary runs have been made on both traditional agriculture and switchgrass for biomass. Preliminary runs have been made on both the normal and dustbowl climates. The input and output numbers are being reviewed. However, it is premature to list those results at this time. Early indications are as expected. Biomass production reduces both erosion and runoff. The preliminary results also indicate the climate scenario of the dustbowl may have a larger impact on switchgrass production than on traditional yields. However, no runs have not been made at elevated CO_2 levels utilizing the models ability to simulate evapotranspiration sensitivities to CO_2 levels.

Manuscripts and Presentations: The first year has been dedicated to obtaining the data and setting up the model runs, therefore no manuscripts or presentations have been written or given to date on this project.

Student participation: The first year of the project did not use students. Plans are to involve students in the crop simulation, watershed scenarios and regional economic analysis in the second and third years.

Scaling in a Spatially Explicit Model of Ecological Response to Global Change

George P. Malanson, Marc P. Armstrong, David M. Cairns
University of Iowa

Objectives: Spatial scaling affects the response of computer simulations of vegetation to fragmentation, barriers, and corridors in the landscape during periods of climatic change. We use a computer simulation model of the dynamic processes of dispersal, establishment, growth, and death of forest trees in a spatially explicit framework to show that the spatial configuration of landscapes controls their reproduction. Three general factors are studied that affect forest dynamics and structure: climatic range, dispersal abilities, and spatial structure. In this research we implement a multi-cell simulation in which we systematically alter the areas represented by each cell in order to elucidate the problems of scaling spatial pattern and process in simulations. The objective of this research is to investigate the consequences of changing the spatial scale of representation of a multi-cell grid model from the landscape to the regional level.

Products: (1) An understanding of the relative effects of the length of an environmental gradient of climate included in simulations. (2) An understanding of the effects of the step size in an environmental gradient for gradients of different lengths. (3) Identification of the effects of different kinds and degrees of landscape fragmentation on simulation results. (4) An outline of steps needed to incorporate refined information on species dispersal in fragmented landscapes into models at progressively coarser spatial resolutions.

Approach: Our modification of the JABOWA-FORET simulation model, the Module Of Spatially Explicit Landscapes (MOSEL) is used as the principle vehicle for conducting simulation runs. Several factors are held constant through all runs: the initial conditions and the amount of climatic change are constant, except for the control case of no climatic change. The standard inputs for tree species adaptations will be used in a modified form. The original model represented a single 10x10 m stand of trees. We use these stands to represent a surrounding area of forest. For this research we begin with a 64x64 cell grid. Each simulation is run for 500 yr. and includes 75 of the dominant tree species of eastern North America.

Over this grid we superimpose an initial north-south gradient of growing degree days (GDD; summed above 4.4^{0} C base) and an east-west gradient of moisture. For the longest gradient the coldest row begins with a mean of 600 GDD while the warmest is at 5600. The west - east gradient is given by the simulation parameter WILT (WILT =(PET-AET)/PET), which we change from a 0.10 to 0.01 for the longest gradient. For a short gradient the range of degree days is 1850 to 4350 (WILT remains the same). For a trial with no gradient all cells are given a degree day level of 3100 and WILT of .05.

Our method uses a series of dispersal rules that apply to the major dispersal types: gravity, wind, and animals. Considering a range of dispersal types is important because it allows us to examine different responses to scale change. To simulate dispersal by gravity we assume that any species producing seed on a site will have potential replacement on that site. Wind dispersal is modeled as a negative exponential decay away from each source cell. Zoochory is also modeled using a probability given by a negative exponential decay away from source cells for three types, which we conceptualize as mammal, scrub-bird, and bluejay. For each plot the simulation model calculates whether a seed source is extant based on presence of individuals of reproductive age by species and probability of a seed crop in a given year. The model then calculates the seed rain to surrounding plots.

In order to assess the effects of different dispersal distances as well as different amounts of environmental change across the grid, it was necessary to obtain improved estimates of the dispersal functions of the species. We analyze the effects of dispersal probability ($p=cd^{-a}$), generation time, seed crop probability, and varying proportions and patterns of landscape fragmentation on migration rate.

Comparisons are made with rates inferred for migrations based on isopols of species range changes in the Holocene. We began with a 5,000 cell transect representing 10 x 50,000 m continuous plane of forest, but with trees only on the first cell; in successive runs we fragmented this grid in the following ways: regularly fragmented, with every third cell uninhabitable or every third cell habitable; randomly fragmented, with 1/3 and 2/3 cells uninhabitable; or containing a continuous barrier in the middle with 100, 200, 400, or 800 cells uninhabitable (the barriers are 1, 2, 4, or 8 km). The number of years until trees reached the end of the transect was used to determine the mean migration rate (m yr^{-1}) for the 25 replicate runs of each combination of parameters.

Results to Date: The results for increasing the length of the gradient indicate that the amount of environmental difference represented in a grid affects the outcome. We analyzed the species diversity predicted by the model. With no gradient, only 3 species are extant in the entire grid (gamma diversity) and the mean diversity per cell (alpha diversity) is 1.36 (Figure 1). With a short gradient, the gamma diversity is 14 and the alpha diversity is 3.08 (Figure 2). With a long gradient the gamma diversity is again 14, but the mean alpha diversity is 2.58 (Figure 3). With no gradient diversity is limited because few species are highly adapted and competitive for the chosen environment; for the short gradient diversity is high because more species can be accommodated and for those species more cells with a similar habitat are available; for the long gradient, although more species can be accommodated, each cell is more distinct from the others and the possibility of extinction for narrowly specialized species is greater; alternatively, the long gradient may be species poor because it contains more of the coldest area simulated, which supports fewer species.

When cells are grouped so that the environmental gradient in either directions is represented by 64, 16, and 8 steps (Figures 3, 4, 5), the effect on diversity is negligible. One can see a pattern developing along the gradient of degree days, but it is not expressed in the summary diversity results.

For the simulations of migration rates, the effects of dispersal probability are revealed in graphs of migration rate over the exponent **a** for the alternative conditions simulated (e.g. Figure 6). Differences due to generation time and fragmentation are greater at the higher dispersal probabilities; at low probabilities absolute differences, although small, are still distinct. The effects of fragmentation are variable (Figure 7). In general, 1/3 fragmentation in both a random and regular pattern lowers the migration rate slightly. At 2/3 fragmentation the effect is more distinct. The additional effect is greatest with shorter generation times. The effect of single large barriers is not seen for small barriers, and at up to 4 km no difference in rate is seen. The barrier effect does become distinct at 8 km, but the pattern revealed is unexpected. With the smaller barriers, slight differences from the continuous case are seen at the higher exponents, and, as with the other variables, effects are masked where the dispersal probability is low. With the larger barrier, however, the absolute effects, while slightly greater at the higher dispersal probabilities, are also clear at the lower ones.

To adjust these rates for different lengths of environmental gradients (and thus distances) represented by the step from cell to cell will require additional research. We have begun to examine how much the migration rate will change if the distances are altered. The probability of dispersal cannot simply be reduced by the same proportion that the distance is increased (i.e., halving the probability for a doubling of distance does not produce the same rate). We have identified the complexity and degree of difference in order to derive an single function for altering dispersal probability for given inter-cell distance.

Manuscripts in preparation, in press, and submitted:

Malanson, G.P. Effects of dispersal and mortality on diversity in a forest stand model. Ecological Modelling, in press.

Malanson, G.P. & Cairns, D.M. Effects of dispersal, population delays, and forest fragmentation on tree migration rates. submitted to Journal of Biogeography.

Malanson, G.P., Cairns, D.M. and Armstrong, M.P. Scaling in a spatially explicit ecological model. in preparation.

Presentations:

Malanson, G.P. & D.M. Cairns. Calibrating dispersal in a simulation of fragmented forest dynamics. U.S. Landscape Ecology Symposium, Minneapolis, April, 1995.

Student participation: David M. Cairns 50%.

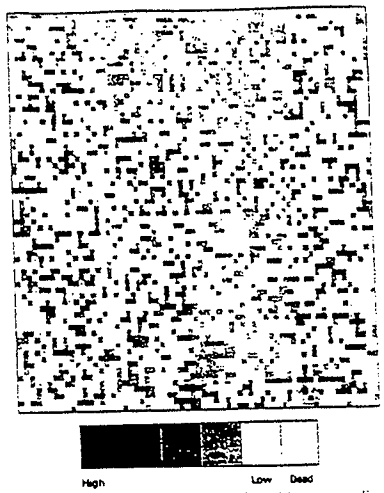


Figure 1. Diversity on the grid with no gradient.

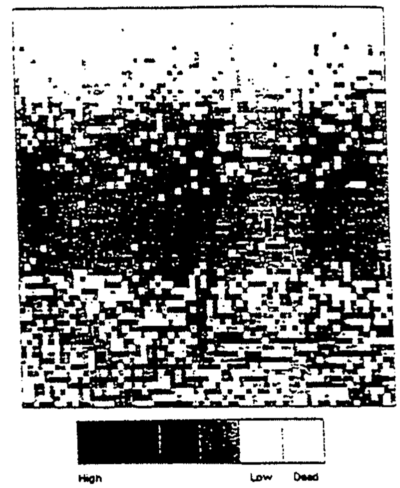


Figure 2. Diversity on the grid with a short gradient (64 steps).

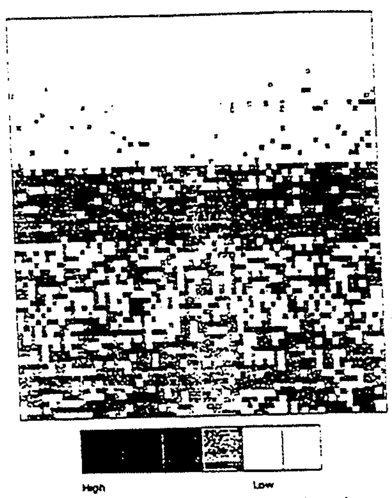


Figure 4. Diversity on the grid with a long gradient grouped into 16 steps.

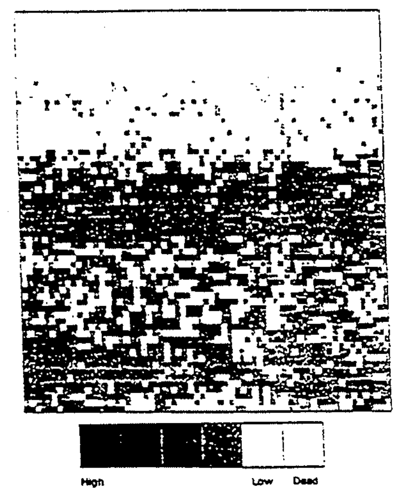


Figure 3. Diversity on the grid with a long gradient (64 steps).

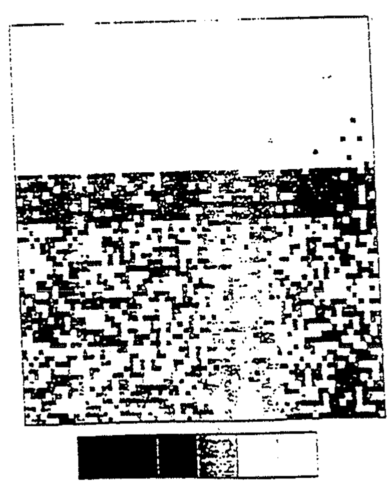


Figure 5. Diversity on the grid with a long gradient grouped into 8 steps.

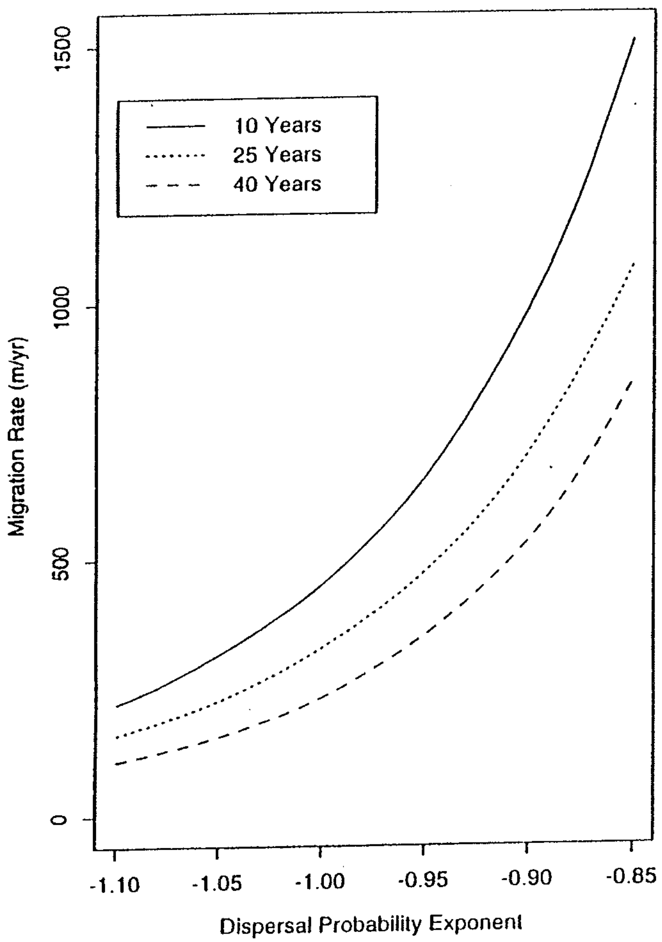


Figure 6. Migration rate varies for dispersal probability exponent and generation time.

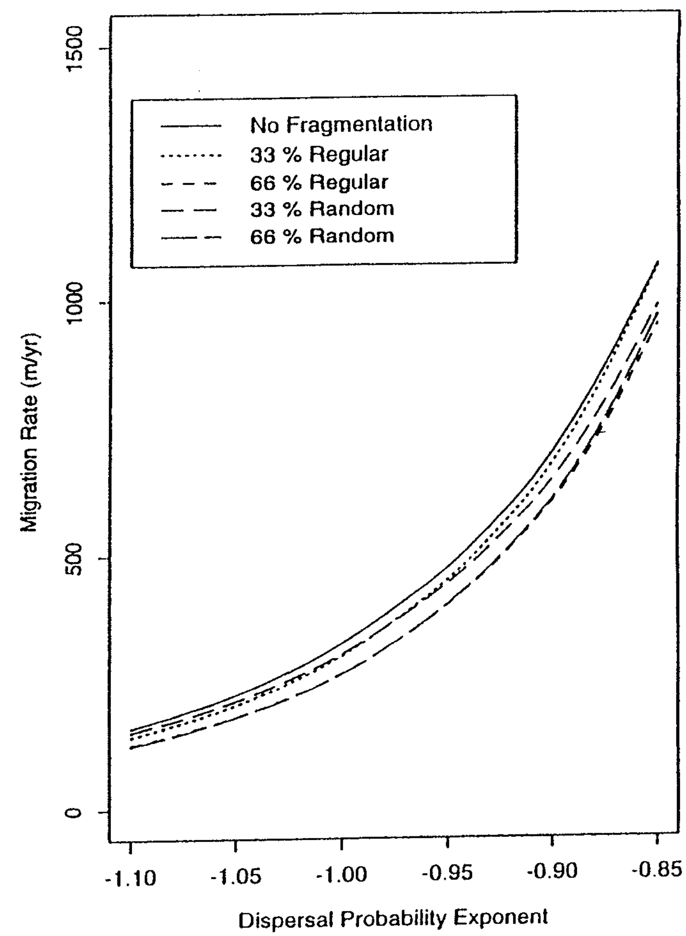


Figure 7. Migration rate varies little for different types of fragmentation.

Modeling the Effect of Global Change on Grassland Distribution and Productivity at Landscape to Regional Scales

Ronald Neilson, James Lenihan and Christopher Daly; Oregon State University
Dennis Ojima; Colorado State University

Objectives: The main objectives of our research are to assemble and implement a linked MAPSS/CENTURY modeling system in the central grasslands region, and assess effects of changes in climate and disturbance on grassland vegetation and ecosystem function at landscape to regional scales.

The proposed research seeks to answer two questions: (1) how will hydrology, nutrient cycling, and disturbance interact with climatically-induced changes in forest and rangeland distribution to alter water and energy fluxes; and (2) do simulations of climate-induced vegetation changes produce similar predictions of altered forest and rangeland distribution and water and energy fluxes when calculated at scales ranging from 50 m up to 50 km?

Ecosystems are not likely to move as a unit in response to climate change; rather, individual functional groups (e.g., C_3 and C_4 grasses or trees) will probably disassociate, reassembling in new combinations. It is therefore likely that the anticipated change in the global climate will have direct, complex impacts on ecosystems across the country. Changes in these biotic assemblages will, in turn, modify ecosystem properties that regulate the release and uptake of many "greenhouse" gases, as well as control the hydrology and surface energy balances. These processes are critical determinants of our global climate, and insufficient attention has been paid to the ways in which these biological attributes interact with global processes, and the scales at which these interactions operate.

Products: A complete series of environmental datasets suitable for use in a wide range of hydro-ecological modeling activities will be generated for Wind Cave National Park. These datasets will include two water years of mapped daily climatic parameters, as well as soils and vegetation maps. A fully calibrated, hybrid MAPSS/CENTURY model will be assembled. The model will provide state-of-the-science assessments of the effects of future climate and disturbance regimes on grassland vegetation and ecosystem function at landscape to regional scales in the central grasslands region. At least two journal articles describing the methods and results from this project will be prepared and submitted to peer-reviewed journals. Included will be an article describing the results from applications of the MAPSS/CENTURY hybrid to standard $2XCO_2$ scenarios from GCMs, and more regionally accurate scenarios derived from applications of the RAMS model with GCM boundary conditions (being conducted as part of another project).

Approach: Wind Cave National Park is the primary test site for this modeling project because of the diversity of plant communities and the availability of research data from ongoing and past research studies. The area is primarily a mixed grass prairie with ponderosa pine covering many of the bluffs and interdigitating with the prairie. The topographic setting is of rolling hills with elevations ranging from 1090 to 1530 m. The distribution of forest and grassland communities appears to be determined by soil depth and moisture conditions. Fire and grazing regimes also play an important role in determining the establishment and composition of the plant communities.

<u>Development of landscape-scale environmental datasets</u>: A digital terrain grid, or digital elevation model (DEM) of the Wind Cave area will serve as a base map. Gridded model inputs of climate (i.e., monthly and daily temperature, precipitation, vapor pressure, wind speed, and solar radiation) will be generated for the Wind Cave area for water years 1993 (October 1992 - September 1993) and 1994 (October 1993 - September 1994). This period encompasses the two field seasons of CSU field data collection, which will provide important vegetation data for model calibration and evaluation.

Model assembly, calibration, and evaluation for landscape and regional scales: We envision the coupling of MAPSS and CENTURY proceeding in three steps. The first step will be a loose coupling of the models. Separate applications of 1-D MAPSS and CENTURY will be made to the central grasslands region for current climate and selected future climate scenarios, with the biogeographical output from MAPSS providing a vegetation type for CENTURY. The next step will be the implementation of selected CENTURY modules into MAPSS-Watershed (MAPSS-W). Of highest priority are modules for determining growth rates of tree, shrub, and grass life forms, and hydrologic algorithms. The final step will be to link 1-D MAPSS and CENTURY for regional-scale assessments.

Assessment of climate and disturbance impacts: The MAPSS/CENTURY hybrids will be applied to various scenarios of climate change and disturbance regimes at landscape and regional scales. The objective will be to identify the relative importance of different climate and disturbance parameters in producing changes in modeled vegetation and function at varying scales.

Results to Date: As part of his Ph.D. dissertation work, Christopher Daly completed the initial development and calibration of MAPSS-W (MAPSS-Watershed), capable of simulating the three-dimensional transport of subsurface water in small catchments. The model was calibrated and evaluated over two water years in the Reynolds Creek watershed, a USDA-ARS (Agricultural Research Service) basin located in the Owyhee Mountains of southwestern Idaho. Results indicate the model does an excellent job of predicting non-woody leaf area, daily runoff from the basin, and other hydrologic features. MAPSS-W and CENTURY will be linked for landscape-scale assessment of climate change effects at Wind Cave National Park.

The preparation of environmental datasets for Wind Cave National Park is largely complete. Monthly maps of minimum and maximum temperature, precipitation, vapor pressure, wind speed, and solar radiation were prepared for WY93 and WY94. Daily maps were developed using the monthly maps as bases, and treating the daily variations as anomalies or proportions of the monthly values. This method was used successfully by Daly (1994) at Reynolds Creek. Climate data for the park were extremely limited, with only precipitation and temperature available at park headquarters. Data for other parameters were obtained from stations in the Black Hills region, drawing heavily on observations from Rapid City. Thus, methods used for mapping climatic parameters were necessarily simple, but sensitive to the topographic diversity in the park whenever possible. Emphasis was placed on simulating the complex radiation and temperature regimes, which are thought to contribute to the patterns of vegetation in the park.

DEM: A digital elevation model (DEM) with a cell size of 50 m was obtained from the EROS Data Center to serve as a base map. The DEM was checked for accuracy and registration problems by overlaying USGS stream networks. A modeling region encompassing Wind cave and vicinity was selected, and measures 17 x 21 km.

Precipitation: Daily precipitation data were available at park headquarters. A qualitative sense of the patterns of precipitation elsewhere in the park was obtained from temporary raingauges operated for a short time in the summer of 1993 as part of the National Biological Service CEGR-1 project. Although very spotty and uncertain, the measured precipitation patterns appeared to be responding to broadly-defined terrain features with a scale on the order of 4 km. This large-scale response pattern had been observed previously in PRISM precipitation modeling work in the western U.S. (Daly et al. 1994). To provide a suitable base terrain grid for precipitation mapping, the 50-m DEM was smoothed to an effective scale of 4000 m using a modified Barnes (1964) filter. The CEGR-1 network was used as a rough guide for determining an approximate relationship between the smoothed DEM elevation and precipitation across the park. Setting precipitation at headquarters at 100% each month, precipitation varied from 85% in the low terrain to the southeast to 120% in the mountains to the northwest.

Solar Radiation: No data were available in the park. The radiation climatology for flat sites was approximated with data from Rapid City (Caputa). However, radiation varies appreciably over the park as a result of the variety of topographic exposures. This variability was simulated by calculating direct and diffuse beam radiation for each pixel, accounting for pixel orientation, slope, surrounding horizon and ratio of diffuse to direct beam radiation (Frew, 1990). The ratio of diffuse to direct beam is a function of atmospheric transmissivity, usually due to cloudiness (Bristow and Campbell 1984). Transmissivity was inferred from the difference between actual daily radiation in Rapid City and a hypothetical "clear sky" radiation (Frew, 1990) at the same location. Resulting maps of total radiation in the park show that on clear, summer days, shady north slopes received up to 40% less radiation than sunny south slopes.

Temperature: Temperature data in the park were available at headquarters. Regional lapse rates of minimum and maximum temperature with elevation were determined through a piecewise linear regression of measurements at Hot Springs (low elevation, 25 km south), park headquarters (middle elevation), and Custer (high elevation, 25 km northwest). The regional lapse of temperature with elevation was strongly negative in spring, summer and fall, but was typically flat or positive during wintertime inversion events. In addition, local maximum temperature is thought to vary as a function of small-scale, topographically-driven variations in direct solar radiation. Based on empirical data, shady, north-facing slopes were assumed to have a maximum temperature of up to 2.5 degrees C cooler than a level pixel at the same elevation, with sunny, south-facing slopes being up to 2.5 degrees C warmer. Minimum temperature does not appear to vary in a predictable way on different slope exposures (Running, 1985). Topographic differences in temperature were greatest in summer and least in winter, because of the comparatively large incident energy available in summer.

Wind Speed: No wind speed data were available in the park. Measurements at Rapid City (Caputa) were used as wind speed estimates throughout the park. A wind model would have been necessary to characterize wind flow patterns in and around the terrain features of Wind Cave, but such modeling was out of the scope of this study. Mean daily wind speeds were typically greatest in the winter and spring (4-8 m/s), and least in the summer (1-5 m/s).

Vapor Pressure: Daily relative humidity was estimated from measurements at Rapid City (Caputa), and used in conjunction with mean daily temperature (average of maximum and minimum temperature) to calculate vapor pressure for each pixel in the region (Frew, 1990). Vapor pressure ranged from less than 400 Pa in winter to over 1250 Pa in summer, and tended to be lower in the northwest mountains due to lower temperatures.

Woody Leaf Area: Woody LAI was estimated using Landsat multispectral scanner (MSS) images of the area obtained from the EROS Data Center. A MSS band 5 image taken on 22 June 1973 corresponded well to the distribution of forest cover in the region. Using the forest cover shading on a topographic map as a guide, the approximate band-5 reflectance that matched the forest/no forest boundary was estimated and a raster "mask" of forested areas constructed. For areas having forest cover, functional (all-sided) woody LAI was estimated using NDVI -- (band 7 - band 5) / (band 7 + band 5) -- from the same June image. The NDVI was scaled to LAI by setting the forested pixel with the highest NDVI to an LAI of 8 and the forested pixel with the lowest NDVI to an LAI of 2 (Kaufman et al. 1982).

Soils: A map of soil associations for the park was obtained from the STATSGO (Soil Conservation Service) soils database. This are currently being combined with soil pit data taken in the CEGR-1 field project to produce raster maps of soil depth and texture.

Presentations:

Daly, C. 1995. Modeling climate, vegetation, and water balance in the Reynolds Creek watershed. Presented at the USDA Agricultural Research Service Northwest Watershed Research Center, Boise, ID, June, 1995.

Daly, C. and R.P. Neilson. 1995. Spatially-explicit simulation of climate-induced leaf area and water balance in a small, mountainous watershed. Presented at the annual meeting of the Association of American Geographers, Chicago, IL, March, 1995.

Daly, C. and R.P. Neilson. 1995. Update of landscape-scale modeling activities in the DOE-NIGEC project. Presented at the annual meeting of the National Biological Service Central Grasslands Global Change project, Fort Collins, CO, January, 1995.

Daly, C. 1994. Modeling climate, vegetation, and water balance at landscape to regional scales. Ph.D. defense seminar, Oregon State University, September, 1994.

Daly, C. and R.P. Neilson. 1994. Landscape-scale simulation of climate-induced water balance and vegetation distribution in the Reynolds Creek watershed, Idaho. Presented at the annual meeting of the Ecological Society of America, Knoxville, TN, August, 1994.

References:

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Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33:140-158.

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Kaufman, M.R., C.B. Edminster, and C.A. Troendle. Leaf area determinations for subalpine tree species in the central Rocky Mountains. USDA Forest Service Research Paper RM-238, 7 pp.

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Carbon, Water, and Energy Fluxes from a Tallgrass Prairie: A Long-term Investigation of Environmental, Biological, and Land Management Factors

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Objectives: Increasing concentrations of atmospheric CO_2 could have an enormous effect on biogeochemical cycling in the biosphere by inducing climate change and by directly affecting plant processes within ecosystems. Thus, understanding the factors that govern the earth C budget, and how these factors might respond to environmental permutations or changes in land use, is vital if we are to prepare for the future. Unfortunately, long-term measurements of carbon, water, and energy fluxes from the Earth's major ecosystems are not available. Given that grasslands may compose up to 50% of the Earth's terrestrial surface, research on the magnitude and mechanisms of trace gas fluxes from this ecosystem is critical if we are to quantify and predict the effect of climate change at regional or global scales.

The main objective of the experiment is to evaluate the flux of carbon, water, and energy from a tallgrass prairie over an extended time period, and determine the effect of environmental, biological, and land management (i.e., burning, grazing) factors on these fluxes.

Products: (1) An understanding of the relationships between the carbon and water budget, and how climate change and atmospheric CO_2 might influence these relationships; (2) Assessment of burning and grazing practices that affect the long-term carbon, water and energy budgets; (3) Examination of plant and soil processes that govern net carbon exchange from the prairie and how these processes can be scaled or modeled to evaluate the ecosystems role in a changing global environment (4) Estimation of the prairies role as a source or sink for atmospheric carbon; (5) Comparison of carbon and water exchange rates from the prairie with fluxes from other ecosystems?; (6) Assessment of measurement techniques for monitoring trace gas fluxes during long-term experiments; and (7) a historical database for the development and verification of regional biogeochemical models.

Approach: Meteorological stations will be established on the Konza Prairie Research Natural Area (KPRNA) that would provide continuous long-term (i.e., 10 yr.) measurements of CO_2, water vapor, and energy exchange. Measurement stations would be operated on three watersheds with differing land management regimes: (1) burned annually, (2) burned every four years, and (3) burned and grazed annually. Each measurement facility will consist of a 9m-tall meteorological tower, a small supplemental tower, underground bunker, and supporting equipment. The main tower will support a sonic anemometer, gas sampling intakes for conditional sampling and gradient methods, and other basic meteorological sensors. The supplemental mast will support a net radiometer and infrared transducer, so that the sensors will have an unobstructed view of the surface. The underground bunker will house the gas analyzers, data acquisition system, and supporting equipment (e.g., calibration gases, batteries, etc.).

The measurement stations have been designed to provide accurate and redundant measurements of carbon and water flux while minimizing costs and maintenance. Carbon dioxide and water vapor fluxes from the surface will be initially measured using four different micrometeorological techniques, including: (1) Bowen ratio, (2) modified Bowen ratio, (3) conditional sampling (i.e., relaxed eddy accumulation), and (4) aerodynamic. During the first year of operation, research will be conducted to determine which method best suits the needs of the NIGEC project. Once a favored technique or group of techniques is determined, then that method will be used for the remainder of the study. Additionally, a wide range of other environmental parameters will be monitored, such as photosynthetic, global, and net radiation, wind speed, vapor pressure, temperature, and precipitation.

Measurement of several ancillary site attributes will provide supporting biotic and abiotic information on the underlying biophysical mechanisms affecting mass flux from the prairie. Supporting measurements can be categorized into carbon fluxes, water fluxes, vegetation, and soil components. Soil-surface CO_2 fluxes will be measured to help delineate plant and soil CO_2 fluxes and quantify the importance of soil respiration on the overall carbon budget. Measurements of leaf photosynthesis, leaf water potential, and sap flow will be used to explore the biophysical effect of vegetation on trace gas fluxes. Other measurements will include leaf area indexes, leaf nitrogen content, aboveground biomass, species composition, soil fertility, and soil water content.

Results to Date: During the first year of the project (FY 94), measurement locations were identified on an annual burn and 4-year burn watersheds within the KNPRA. Both sites are located in large lowland areas with representative vegetation and have ample fetch for the boundary layer measurements. Research permits were applied for and received. The vegetation at the sites was characterized and biomass data from previous research in the watershed was catalogued.

The underground concrete bunkers were fabricated and readied for installation. An attempt to install the bunkers in the February 1995 failed because the earth-moving equipment being used to excavate the bunker pits could not traverse the prairie when the soil was moist. The bunkers will be installed in August or September of 1995.

The design of the instrumentation for measuring CO_2 and water vapor flux was finalized. Both Bowen ratio and Eddy accumulation techniques will be used simultaneously to provide a redundant and robust measurement of boundary layer fluxes. Additionally, every attempt was made to design a system that required minimal maintenance and did not have a large post-processing requirement. A prototype of the flux instrumentation was constructed as part of a study funded by the USDA titled "Carbon and Water Fluxes From Irrigated Corn: A Field Scale Long-Term Study". This system will be evaluated over a fully developed corn canopy in the summer of 1995. Results from these tests will assist in the construction and operation of the NIGEC measurement stations.

Presentations:

Ham, J.M. and C.E. Owensby. 1994. Scaling CO_2-Induced Stomatal Closure to Regional Levels: Bouchet's Hypothesis Revisited. Am. Soc. Agron. Annual Meetings. Seattle, WA.

Bremer, D.J., J.M. Ham, and C.E. Owensby. 1994. Transpiration from a tallgrass prairie exposed to elevated and ambient atmospheric CO_2. Am. Soc. Agron. Annual Meetings. Seattle, WA.

Ham, J.M., J.M. Tarara and G.J. Kluitenberg. 1994. Heat-pulse methods for measuring soil heat flux and changes in water content near the soil surface. Annual meetings of the American Geophysical Union, San Francisco CA.

Ham, J.M. 1995. Effect of Water Stress on Net Carbon Exchange From a Prairie Ecosystem Exposed to Ambient and Elevated Atmospheric CO_2. IGBP-GCTE Workshop. Stress Effects on Future Terrestrial Carbon Fluxes. May 14-18. Lake Tahoe, CA.

Student Participation: Dale Bremer 20%; Craig Sharp 50%.

An Integrated Investigation of Carbon Dioxide and Methane Fluxes in Mid-Latitude Prairie Wetlands: Micrometeorological Measurements, Process-Level Studies and Modeling

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Objectives: Our overall objective is to expand the currently limited body of knowledge on surface fluxes of carbon dioxide and methane in mid-latitude prairie wetlands. Consequently, we are measuring surface fluxes of carbon dioxide, methane and energy, and a suite of physical, chemical and biological variables. Process-level studies, designed to quantify factors regulating methane emission, are also being conducted.

Products: We will produce a unique data set on fluxes of carbon dioxide and methane in these relatively unstudied mid-latitude prairie wetlands. Concurrent micrometeorological and chamber flux measurements will allow temporal and spatial variation in fluxes of carbon dioxide and methane to be related to underlying biological and biophysical processes. Process-level models of methane fluxes will be improved and tested.

Approach: During 1993 we investigated 18 potential sites in the Sandhills region of Nebraska and selected Ballards Marsh near Valentine, NE as our study site for detailed, intensive measurements of fluxes of carbon dioxide, methane and energy. The Ballards Marsh site provides an excellent upwind fetch for the micrometeorological measurements and is characterized by three well-defined plant community types. The first is dominated by 2-3 m tall common reed grass (*Phragmites australis*). The second is dominated by 1-2 m tall bulrush (*Scirpus acutus*). The third main community occurs in areas of deeper, open water, where wild rice (*Zizania aquatica*) is the major emergent species and a submergent pondweed (*Potamogeton*) species is very common. Flux measurements at wetland sites require extensive infrastructure (e.g., boardwalks, instrument platforms for micrometeorological instrumentation, platforms for sampling surface carbon dioxide and methane fluxes using chambers). These were installed in 1993 and described in previous progress reports.

Results to Date:

1) Micrometeorological flux measurements:

In 1994, we completed the installation and check-out of eddy correlation and other micrometeorological instrumentation by mid-April. Data collection began on April 19 and continued until October 14. Processing of the data continues at this writing. Some preliminary results, based on real-time raw observations, are included below.

a) Components of surface energy balance: Typical diel courses of energy balance components on a clear day in a *Phragmites*-dominated site are shown in Fig.1. The heat stored in the water and sediment layer (W) was about 30% of net radiation (Rn). During midday, 50% of Rn was partitioned to water vapor flux (LE) and 20% of Rn to sensible heat flux (H). Energy partitioning changed with the development of the vegetation canopy and its senescence, and with the fluctuations in water table elevation. We observed several occurrences of advection of sensible heat, which resulted in enhanced evapotranspiration. In the spring of 1994, we installed instruments to measure the surface energy balance at two other locations (*Scirpus*-dominated and open water) at the Ballards Marsh study site. Details of the diel and seasonal characteristics of energy partitioning in these three main plant community types (i.e., *Phragmites, Scirpus*, open water) are being investigated.

b) Net ecosystem carbon dioxide exchange: We began CO_2 flux measurements on April 19 just before the plants started emerging above the water surface. Until the vegetation reached a canopy height of 0.2-0.5 m (above the water surface) and developed one or two small green leaves in mid-May, the marsh was a net source of atmospheric CO_2, releasing CO_2 at rates of 0.05-0.1 mg m^{-2} s^{-1} throughout the day. In late May, the marsh quickly changed from a source to sink for CO_2. The net uptake of CO_2 during daytime increased rapidly from 0.2 mg m^{-2} s^{-1} in late May to 0.8 mg m^{-2} s^{-1} in August. Typical diel variations in CO_2 flux during the peak growth stage (late July) are shown in Fig.2. The CO_2 flux reached a peak during mid- to late-morning hours. At night, the measured CO_2 flux indicated a release of CO_2 into the atmosphere at rates of about 0.1 mg m^{-2} s^{-1}. In September, magnitudes of both daytime and nighttime CO_2 fluxes decreased rapidly as the vegetation senesced, and the CO_2 exchange between the marsh and the atmosphere approached zero in October.

c) Net methane emission: During the early part of the season (late April-late May) midday methane flux ranged from 100 to 200 mg m^{-2} d^{-1}. During the period from early June to early July, the methane flux increased from 250 to 600 mg m^{-2} d^{-1}. Midday methane flux reached a peak during August-early September and varied from 600 to 1200 mg m^{-2} d^{-1}. Toward the end of the season (mid September-mid October), with senescing vegetation and falling temperatures, methane flux decreased to small values (100-350 mg m^{-2} d^{-1}). Significant diel variation, as found in the 1993 season, was repeatedly observed throughout the 1994 season. Typical diel patterns in methane flux are shown on two consecutive days in late July, 1994 (Fig. 3). Methane flux usually reached a peak during mid to late morning hours. During the stage of peak growth (July-August), daytime CH_4 flux typically ranged from 300 to 1000 mg m^{-2} d^{-1}. Nighttime flux, however, remained relatively constant ($\approx$ 250-350 mg m^{-2} d^{-1}). Nighttime methane emission averaged on a daily basis also showed distinct seasonal variation and seemed to correlate strongly with changes in sediment/water temperature.

2) Chamber measurement of surface carbon dioxide flux:

Surface fluxes were measured using a chamber from May to October, 1994 at the Ballards Marsh site at platform locations along two transects approximately 200 m east and west of the main boardwalk (leading to the eddy correlation tower). Platforms were located in *Phragmites*- and *Scirpus*-dominated vegetation communities. Surface CO_2 fluxes were small early in the season and reached a peak in the middle of August after which they declined. These fluxes appear to be correlated with canopy foliage area index and water column temperatures. Surface CO_2 fluxes in *Phragmites* communities ranged from 0.03 mg m^{-2} s^{-1} in mid-May to 0.13 mg m^{-2} s^{-1} in mid-August. Surface fluxes in *Scirpus* communities ranged from 0.03 mg m^{-2} s^{-1} in early May to 0.09 mg m^{-2} s^{-1} in mid-August.

3) Chamber measurement of individual leaf gas exchange:

We quantified single leaf gas exchange properties in detail for *Phragmites australis* and *Scirpus acutus*. Selected gas exchange measurements were also made on *Typha latifolia*. Measurements were initiated on small leaves in May and continued into early October. Some preliminary results are discussed below. The response of net CO_2 assimilation to incident light intensity was determined throughout the growing season for *Phragmites* and *Scirpus*. Assimilation rates for *Phragmites* under full sunlight were approximately 15 μmol m^{-2} s^{-1} in mid-June and reached 20 μmol m^{-2} s^{-1} by mid-July (Note: 1 μmol CO_2 m^{-2} s^{-1} = 0.044 mg CO_2 m^{-2} s^{-1}). These rates decreased to around 12 μmol m^{-2} s^{-1} by mid-September. Light saturation was not always evidenced in *Phragmites*; assimilation rates tended to increase up to full light intensities (photosynthetically active radiation, Q_p = 2000 μmol m^{-2} s^{-1}). Stomatal conductances under full sunlight were 0.4 mol m^{-2} s^{-1} for the mid-July period. In general, assimilation rates and stomatal conductances were smaller in *Scirpus* with net assimilation peaking in mid-July with rates near 15 μmol m^{-2} s^{-1} and stomatal conductance for the same period near 0.3 mol m^{-2} s^{-1}. *Scirpus* also exhibited a higher degree of light saturation than *Phragmites*, with saturation at 1000 - 1200 μmol m^{-2} s^{-1}. Under full sunlight in July, *Typha* had net assimilation rates of 22 μmol m^{-2} s^{-1} and stomatal conductances of 0.5 mol m^{-2} s^{-1}. The responses of net assimilation rate to internal CO_2 concentration

(C_i) in all three species were fairly typical for C_3 species. Initial slopes (carboxylation efficiencies) and C_i at ambient CO_2 concentrations were highly dependent upon incident light intensity. The response of dark respiration to leaf temperature was determined for *Phragmites* and *Scirpus*. Respiration rates at 25 C were 1.5 μmol m^{-2} s^{-1} in *Phragmites* and 0.7 μmol m^{-2} s^{-1} in *Scirpus*. In general, respiration rates were higher in *Phragmites* than in *Scirpus*.

4) Chamber measurement of carbon dioxide and methane flux and experimental manipulation studies:

During April, 1994, we established sixteen plots (each $4 m^2$) along transects to the east and west of the micrometeorological tower complex. Four of these were dominated by *Scirpus*, the other twelve by *Phragmites*. Of the *Phragmites* plots, three were used as experimental controls, three more as disturbance controls (associated with establishment of limno-corrals) and the last six were used for experimental manipulations. The nine limno-corrals were established by fencing in the plot using a doubled-over polyethylene tarp to decrease mixing of water within the plot with that outside the plot in order to retain treatments. In order to assess the impact of carbon substrate quantity and quality on CH_4 production and emission rates, we added carbon (as wheat straw) alone or in combination with nitrogen (as urea). The experimental manipulation design had a modified latin square design in which each treatment combination was paired with every other treatment combination at one of the six *Phragmites* platforms, giving three replicates of each treatment. All plots were accessed from elevated platforms in order to minimize disturbance.

We developed a new, temperature-controlled chamber system to enable whole-system measurements of CH_4 and CO_2 flux in the 4 m^2 experimental plots with minimal disturbance. These consisted of a 3 m tall x 1 m^2 transparent teflon "tent" (FEP) supported by a central mast and three PVC hoops to maintain the chamber shape. In conjunction with these whole-system chamber measurements of CH_4 and CO_2 flux, we measured open-water emissions using floating 20 L opaque white polyethylene chambers. Ebullition was measured using 24-hr accumulations in inverted, 20 cm diameter polyethylene funnels. We also measured temperatures and porewater CH_4 and CO_2 concentration profiles using permanently installed probes which had thermocouples and 2 mm diameter FEP teflon ports at several depths.

Although rates of CH_4 emission and CO_2 uptake, as assessed by the whole-system chamber, were highly variable among plots, some important patterns emerged. The control plots (no corral) had significantly higher ($p<.05$) CH_4 emissions than any of the corralled plots, but no differences were apparent in CO_2 uptake rates. These differences may be attributable to disturbance associated with the corrals and investigator traffic. Experimental carbon and nitrogen (+C+N) additions increased CH_4 emissions slightly, while carbon alone (+C) apparently decreased CH_4 emissions. We are presently analyzing the surface-water CH_4 and CO_2 concentration data to estimate diffusive fluxes using the Stagnant Film Model. Ebullitive fluxes comprised about 10-20% of the total CH_4 flux, although these were more variable than the whole-system chamber fluxes. The +C and +C+N plots had 2-3 times as high rates of CH_4 and CO_2 losses via bubbles as did the remaining plots ($p < .05$). The collectors were located below the floating mat on the +C and +C+N plots, so the bubbles should have come from the sediments. This implies that the carbon additions also affected below-ground processes. Seasonally averaged porewater gas concentration profiles indicated that CH_4 and CO_2 production rates peaked 20-30 cm below the sediment water interface. The CH_4 concentrations peaked about 10 cm higher in the profile with +C or +C+N additions, which may explain some of the apparent differences in ebullitive loss rates.

Training of Graduate Students on this Project:

Burba, Georgiy G. Surface energy balance in a mid-latitude prairie wetland. M.S. Thesis (research in progress). University of Nebraska-Lincoln. 100% on this project. $10,350 per year (graduate research assistantship).

Vanyarkho, Olga. Responses of leaf and canopy gas exchange to environmental factors. M.S. Thesis (research in progress). University of Nebraska-Lincoln. 100% on this project. $10,350 per year (graduate research assistantship).

Presentations:

Vanyarkho, O. and T. J. Arkebauer. Responses of *Phragmites australis* and *Scirpus acutus* leaf and canopy gas exchange to environmental conditions. Ecological Society of America 80th Annual Meeting, Snowbird, Utah, July 31-August 1, 1995.

Valentine, D.W., W.M. Pulliam, E.A. Holland, and D.S. Schimel. An experimental manipulation of methane emissions in a mid-latitude prairie wetland. Ecological Society of America 80th Annual Meeting, Snowbird, Utah, July 31-August 1, 1995.

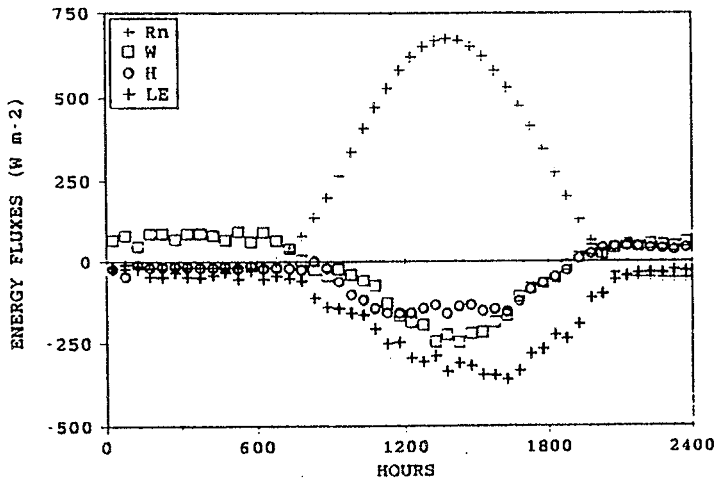

Fig. 1. Components of Surface energy balance: net radiation (Rn), heat storage in water-sediment layer (W), sensible heat flux (H) and water vapor flux (LE).

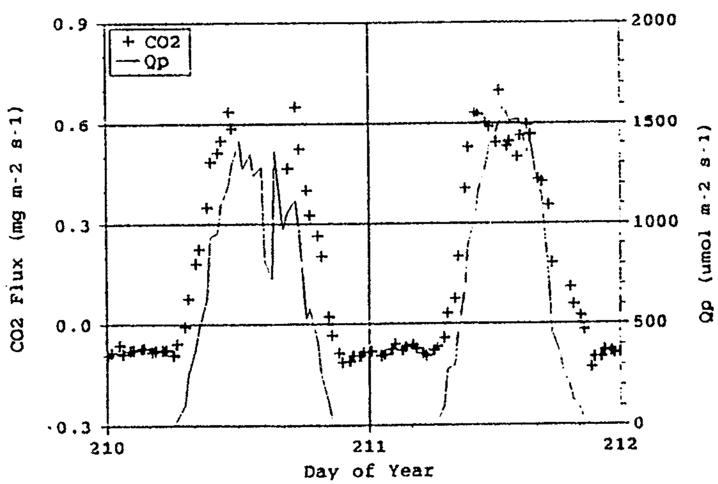

Fig. 2. Diel patterns of carbon dioxide flux and photosynthetically active radiation (Q_p) in late july, 1994.

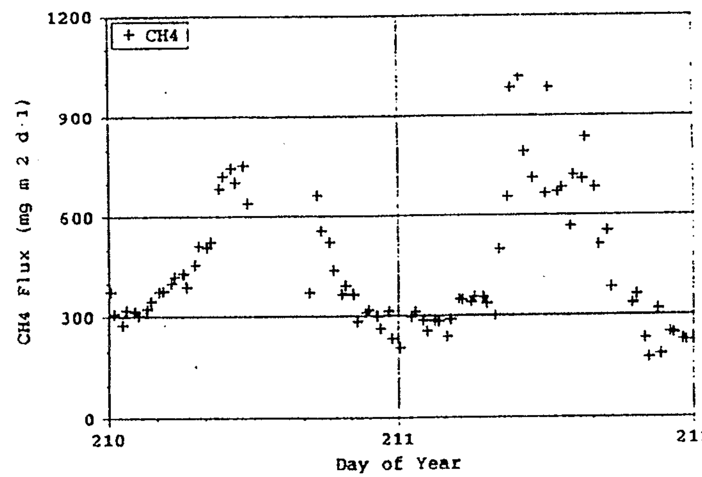

Fig. 3. Diel patterns of methane flux late July, 1994.

Regional Projections of C Dynamics with Global Change in the Central U.S.: Interactive Effects of Management, Climate and Elevated CO_2

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Objectives: The key objective of our research is to separate the interactive effects of climate, elevated CO_2 and management on soil organic matter (SOM) dynamics in the Central U.S. wheat and corn growing regions. We are applying a global change system analysis (Metherell 1992) to a benchmark database being developed as part of the Agroecosystem Science Program at Colorado State University. Another important objective is to provide information that can be used to design experimental studies to test the relative influence of these key factors of global change on soil C responses.

Products: We are producing information on projected SOM dynamics for widely distributed selected sites within the Great Plains of the central North America. To accomplish this we are determining (1) the effects of historical management practices, (2) future effects of current management, (3) effects of current management, with changed climate and CO_2 levels, (4) new management systems which optimize carbon storage and crop production within new climate/CO_2/management situations and , (5) the relative impacts of changed management, CO_2 and climate on agroecosystem C fluxes. This document reports the first of our publishable efforts resulting directly from NIGEC support (Elliott et al., in prep). We expect most of our publishable results to appear in the final year of the project.

Approach: We are using the CENTURY model (Parton et al. 1987) for our work, which is probably the most widely-applied SOM model currently available. The Century model environment has been extensively modified with a new file structure and a preprocessor called Event 100 (Metherell et al. 1993). Event 100 is used to schedule management events and the growth of different crops, and to control the overall execution of the Century model.

The updated Century model was used to simulate C and N dynamics (Metherell 1992) in innovative agricultural systems being field tested at three sites in eastern Colorado (Peterson et al. 1992). The long-term sustainability of the management systems was tested using the historical weather record for the localities of the field experiments. The effect of increased atmospheric CO_2 was tested by making appropriate adjustments to model parameters, while the effect of climate change was examined by either increasing the temperatures and adjusting precipitation amounts in the historical weather record or running the model with weather output from a mesoscale climate model. The results strongly suggest that with appropriate management for the prevailing environment, SOM levels in semiarid agroecosystems in eastern Colorado can be increased or at least stabilized (Metherell et al. 1995).

For our NIGEC project we are obtaining information for the products (listed above) through the following process:

(1) Simulations using Century are being compared to the current status of agricultural systems based upon initial conditions before application of field treatments and the length of time the treatments have been in place.

(2) Projecting future effects of current management allows us to determine the potential impact of a continuation of the current practices without the influence of global change.

(3) We are projecting the effects of current management, with changed climate and CO_2 levels.

(4) Model experiments to optimize management system for carbon storage and crop production are being conducted to determine (a) which of the possible management scenarios will result in the greatest storage of soil C (e.g., wheat-fallow vs. wheat-corn-fallow rotations) and (b) which of the possible management scenarios will result in the greatest crop production.

(5) We are evaluating the relative impacts of management, CO_2, climate and their interaction on C fluxes. Of particular interest is (a) the comparison of the projection of the current management practices (see 2 above) with those same practices run under various climate change scenarios (see 3 above), and (b) comparison of current management under climate change (see 3 above) and new "optimized" management under climate change (see 4 above). Results from these two sets of comparisons allows us to make an assessment of the relative impacts of the direct effects of changing climate and the subsequent indirect effects of changes in management systems that may be better adapted to the new climate and CO_2 conditions.

Results-to-Date Site Choice: We have made model-data comparisons for ten sites; four will be discussed here, (1) Sidney, NE and Sterling, Stratton and Walsh, CO. These sites were chosen to represent a gradient of increasing temperature (4^0 C difference in mean annual temperature north to south) with approximately constant precipitation. The result is a series of sites that span across a gradient of potential evapotranspiration (PET), a key driver of ecosystem behavior in the Great Plains. Soil textures are generally similar but the Colorado sites have a longer history of cultivation (~60 years) than the Nebraska site, which has only been under cultivation for 20 years.

Model-Data Comparisons: Comparisons were made between model output and plant and soil data from the four sites. The data were obtained from a compendium of data from long-term experiments in North America (Paul et al., in press) and data obtained from samples we have taken at the sites based on another research project (Elliott et al. 1994a, Paustian et al. 1995). Analysis at each site consists of multiple steps (Elliott et al. 1994b). The model is run under native vegetation for 7,000 years, allowing SOM levels to reach steady-state for that set of climatic and edaphic driving variables. Then, each site was cultivated and cropped under historic management until the estâblishment of the agricultural experiment. The agricultural experiments, often with several treatments, are simulated until the present time and the results compared with existing plant and soil data.

Often, the only historical plant data are grain yields. Since grain yield is the result of a complex set of determinants, and often quite different in response from vegetative growth, matching grain yield data with Century grain yields is challenging. In addition, yields in the field are reduced by pests, hail and other "acts of God" whose mechanisms are not included in Century, which was primarily designed for analysis of SOM dynamics. Measurements of changes in SOM may be a better test for goodness of fit of Century to existing data. Soil SOM data are also prone to difficulties in sampling and measurement, although we have sampled all of the sites used in this report and feel confident in the results. The fit of simulated vs. observed SOM levels is somewhat better than for grain yield (Fig.1). Some of the "luck of fit" of predicted to observed SOM levels is associated with uncertainty in the previous land-use history (since initial cultivation) at the sites as well as errors in the model estimates of soil C in the native soil prior to cultivation.

Model Analysis: For this report, global change-related variables consisted of alterations of total precipitation, the distribution of this precipitation over the year, temperature (represented by a north-south gradient of sites, Fig.2), choice of cropping system, and elevated CO_2. With increasing adoption of no-tillage management in the Great Plains, more water is available for growth of crops (Peterson et al. 1993) and dryland corn may be successfully worked into the rotation in regions where corn has traditionally been not grown. At each site we simulated no-till management with wheat-fallow (WF), wheat-corn-fallow (WCF) or continuous wheat (W) with N limitations removed by fertilization. Water was varied by changing the total amount and distribution throughout the growing season. Precipitation was varied in each month from 40% to 160% of normal and the seasonal variations consisted of reducing the amount of precipitation during July and August by 0 to 60% and moving this water to May, June, and July. Thus, the water is essentially transferred from the hot and dry post-wheat harvest period, when water is likely to be lost to evaporation, to the wheat growing period. CO_2 was elevated to 700 ppm for some model runs.

Results: Precipitation amounts and distributions were similar across sites (Fig.2) so differences observed in grain yields of wheat in the WF rotation are attributable to differences in temperature. Shoot and root residues entering the soil after harvest (C inputs) show generally the same pattern as grain yield, except that the response to precipitation was less steep (data not shown). Carbon inputs from all three cropping systems were similar at low precipitation levels. The WCF rotation, showing the greatest early response to precipitation but the W treatment had the greatest inputs at the highest precipitation level (Fig.4, data for Stratton only shown). The WF treatment resulted in no change in SOM-C any site except Sidney, where the soil C losses increased with wetter conditions, probably because this site had a shorter history of cultivation (Fig.5). Generally, SOM changes for WCF and W were similar at high precipitation levels but lagged behind in the W treatment under intermediate moisture levels, probably because there were relatively lower C inputs.

Increasingly shifting the precipitation from July and August to April, May and June resulted in greater SOM-C levels in the WF treatment (Fig.6) probably because there were greater C inputs. The same was true to a lesser degree in the W treatment at lower precipitation levels, but the SOM-C levels in the WCF treatment showed no responses to rainfall redistribution (Fig.6). Elevated CO_2 resulted in large increases in SOM-C especially where wheat was grown (Fig.7). Elevated CO_2 had the greatest influence in the continuous wheat at high precipitation levels. There did not appear to be an interaction between the timing of rainfall and cropping system on SOM-C levels (data not shown).

Conclusions: Alterations in cropping systems and elevated CO_2 appear to have a far greater impact on soil C levels than changes in climate under the current management systems. This means that a detailed analysis of the potential success of new cropping systems will be essential for evaluating the impact of global change on soil C sequestration in the Great Plains.

Acknowledgement: We would like to thank Serita Frey for preparation of the figures derived from model output.

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Figure 1. Total Soil Carbon (g m^{-2})

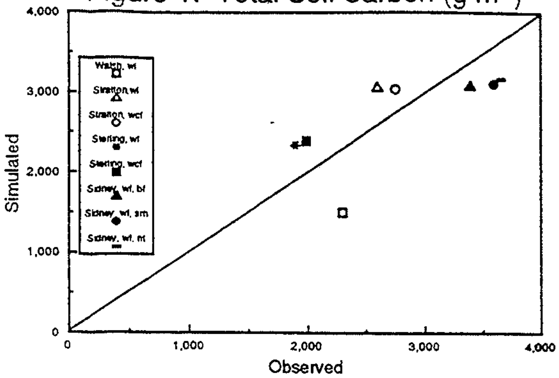


Figure 2. Precipitation (Monthly Average)

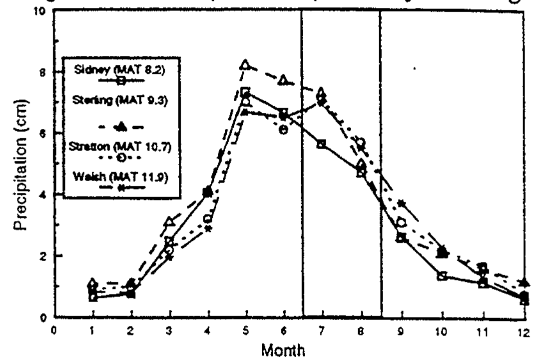


Figure 3. Grain Yield

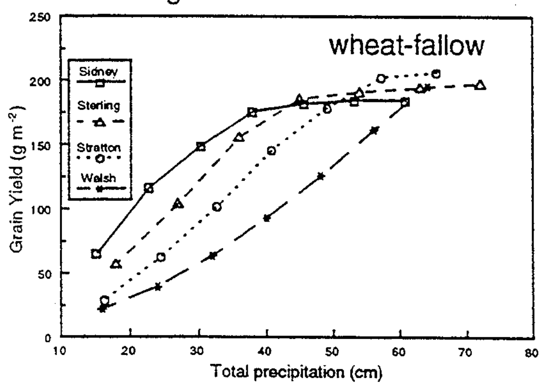


Figure 4. Carbon Inputs

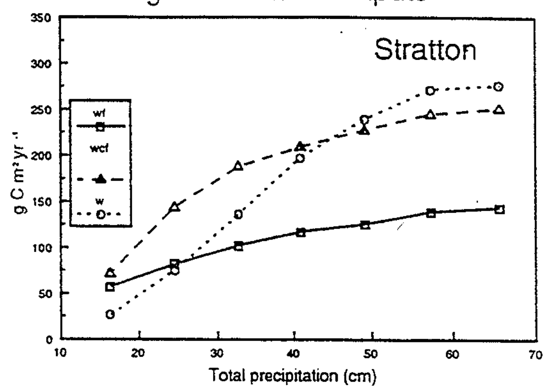


Figure 5. Change in Total Soil Carbon

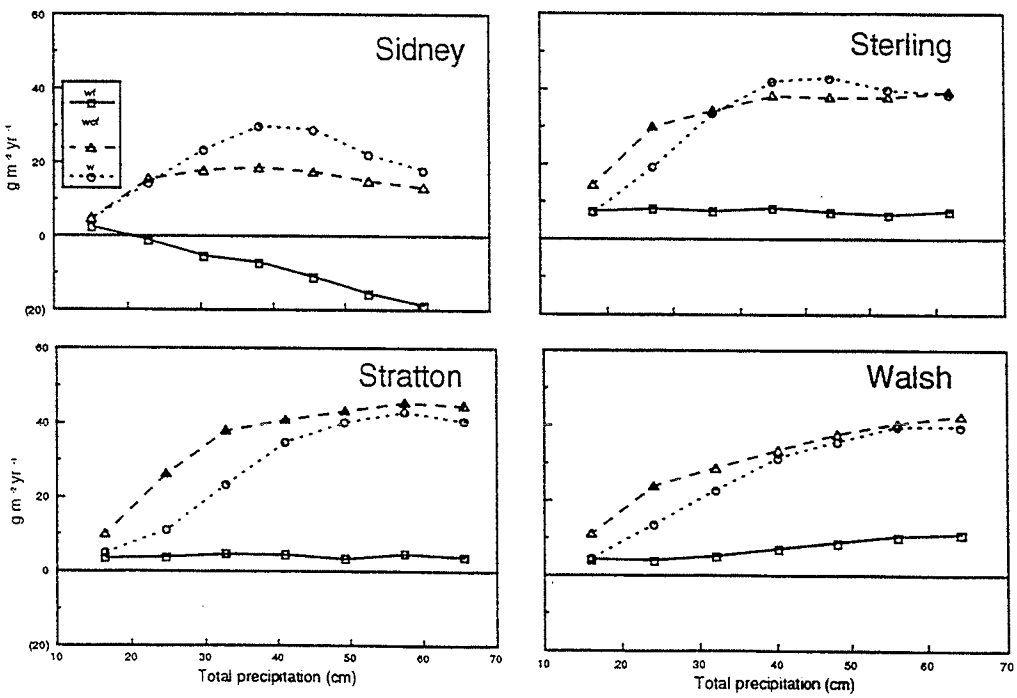


Figure 6. Change in Total Soil Organic Carbon at Stratton

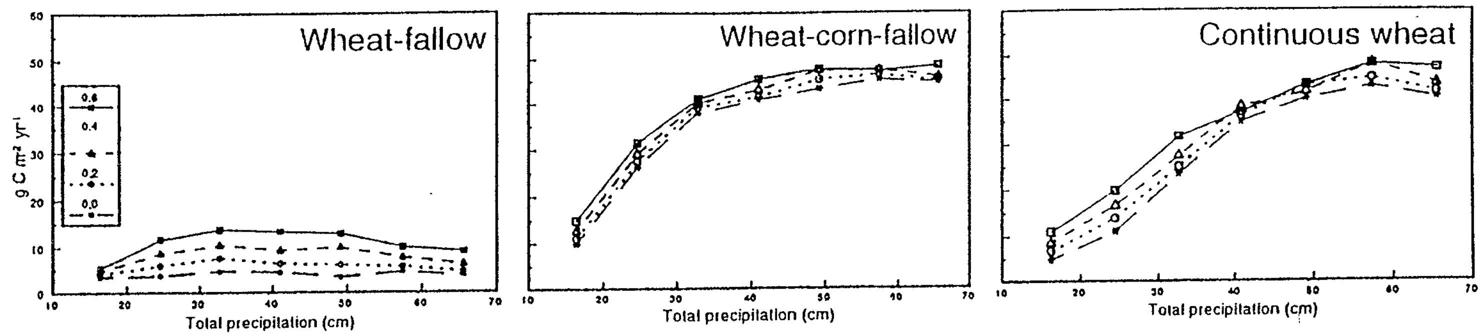
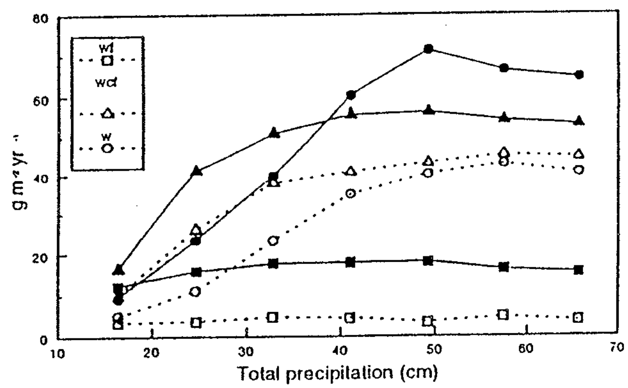


Figure 7. Change in Total Soil Organic Carbon at Stratton

normal CO2 - - - - elevated CO2 ———



Assessment of Climate and Management Induced Directional Changes in Great Plains Vegetation with NDVI and Stable Carbon Isotopes

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Cynthia Cambardella; Iowa State University
Kelly Kindscher; University of Kansas
Dennis Ojima; Colorado State University
Brad Reed; EROS Data Center
Dave Schimel; National Center for Atmospheric Research

Objectives: The carbon isotopic signature, $d^{13}C$ value, quantitatively characterizes the two main photosynthetic systems, C_3 and C_4, in the Great Plains. The ability of stable isotopes of carbon to integrate ecosystem processes, to quantify carbon fluxes from the atmosphere by temperature sensitive photosynthetic types, and to provide isotopic labels which preserve historic and prehistoric carbon sources allows us to examine the response of Great Plains systems to climate change, to management induced directional change in vegetation, and to other human induced perturbations. C_3 and C_4 species have different temperature requirements, and their proportions in the floras at any specific latitude vary in response to temperature and, perhaps, other climate and biogeographic factors.

Our main objective is to determine if today's native grassland systems are in a long-term steady state with climate or the degree to which they depart and the direction in which change is proceeding. We intend to integrate soil fractionation techniques with ecosystem modeling approaches to assess the fluxes of carbon from various SOM fractions, the turnover of these fractions under steady state natural and managed agricultural systems, and the potential for land remediation and the sequestering of carbon. A second objective will establish biophysical attributes to NDVI or other vegetation indices in grasslands and to assess yearly uptake of carbon by the dominant C_3 and C_4 systems in grasslands. A third objective will describe the effects of land management on SOM stability, turnover, and carbon flux. We intend to develop a predictive capability to describe community change, movements of land cover classes, and changes in net carbon flux by each photosynthetic type in response to long-term climate change.

Products: We will describe the land cover classification of grassland types in the Great Plains and interpret the performance of these classes from remotely sensed data. Analyses of these classes and their performances will be assessed with time series of AVHRR-derived reflectance data supplemented with potential production and species composition estimated from the STATSGO data base and field isotopic analyses of selected native prairies across North America. We will secure a fairly dense climate record and provide a prediction of factors controlling the proportional contribution of C_3 and C_4 species to primary production. Land cover classes and their performances across the Great Plains will be interpreted based on this contribution. We intend to describe modern distributions of production by species or photosynthetic types. We will derive the seasonality of production by type and begin to develop estimates of annual carbon uptake by land cover class and photosynthetic type.

In addition to the isotopic analysis across the Great Plains, we will focus on an understanding of the dynamics of SOM changes as a function of land use. We will provide detailed descriptions of SOM changes in native prairie and agriculturally managed systems. This will be based on stable isotopic composition as well as fairly frequent 14-C dating of various SOM fractions from several systems. We intend to quantify the rates at which carbon in SOM of various soil fractions turns over, and we will incorporate this understanding in an implementation of a modified version of CENTURY which will incorporate greater depth dynamics and isotopic balances.

Approach: Our research incorporates several seemingly diverse approaches to the study of Great Plains climate change. Stable isotopes of carbon are used to quantify fluxes from various pools of carbon, mainly atmosphere, plant, and SOM, and to allow us to interpret successional changes in vegetation as well as steady state relationships between SOM isotopes and climate. This requires the analytical capabilities of an isotope ratio mass spectrometer and the SOM fractionation techniques worked out with Cambardella. Remote sensing, mainly AVHRR data, allow us to monitor grassland land cover classes across the Great Plains and at specific sites where biomass and biophysical relationships can be derived. Ultimately we believe this will allow us to calculate production and net carbon flux across what we define as "ecosystem performance types." The integration of our understanding across both time and space is facilitated by modeling of SOM dynamics from our site specific data where we can quantify changes associated with land use as well as place prairie sites in a longer term Holocene perspective.

Soil samples have been obtained from 75 native prairie sites across North America with four to six replicate pooled soil samples stratified by depth. These have been analyzed for bulk stable isotopes following preparation and are still in the process of being carbon dated. Several matched land use systems near Rockefeller Prairie in Kansas and in North Dakota have been examined in detail with particle-size and density fractionation of SOM. The STATSGO data base serves as a source of production estimates as well as contributions by the main species, which we determine for photosynthetic type. These data are aggregated in a GIS system and intersected with climate data and AVHRR-derived land cover classes for further analysis. This analysis includes a detailed set of metric features, e.g., onset period, maximum period, time integrated NDVI, etc. which we can interpret in light of our isotopic estimates of contribution by photosynthetic types. AVHRR data and analyses are performed at the EROS Data Center. Modeling of SOM dynamics is done with a STELLA version of CENTURY to facilitate the isotopic changes which we wish to simulate.

Results-to-Date: Land Cover Analysis: The integration of our field isotopic work, land cover classification, and the STATSGO data base has allowed us to interpret the performance of major grassland land cover classes in the Great Plains. Table 1 summarizes the areal extents and major grass components in these classes and our estimate of percent contribution to production by each photosynthetic type. Note that the contribution by C_4 species varies from 94% in the south to a low of 29% in the north. The classes possess distinct patterns of NDVI with a consistent relative performance across five years of quite variable weather. Production seems largely independent of composition by photosynthetic type but clearly documents an east to west decrease in time integrated NDVI, with, however, a large increase in the time integrated value during 1993 with the high precipitation which reduced NDVI in agricultural classes to the east. The most notable feature is an early onset in land cover classes to the north, classes which are dominated by C_3 species. Apparently, these types are largely excluded in areas south of Nebraska, resulting in a late onset of greenness as C_4 species initiate growth. Variability within classes, relationships with photosynthetic types, and climatic controls over metric features need to be determined.

Climate and Prairie Composition: Both the isotopic data and analysis of STATSGO data have been used to determine the control over contributions to production (as distinct from floristic composition). Isotopic data suggest that the soil is not in steady state with the atmosphere in part because of the anthropogenic signal which is working its way through the profile and into recalcitrant fractions. Many sites, however, also suggest a greater contribution by C_3 species than can be accounted for by the anthropogenic correction. More important, however, both STATSGO and the isotope data show that similar environmental variables are important in determining proportional contribution to production. Table 2 summarizes some data for the surface (A) horizon as well as the horizon which is generally the most positive (usually at a depth around 15 cm). In most analyses proportional contribution by C_4 species is related positively to high temperature during the growing season and precipitation in July and negatively to the low temperature in April. Often sand is significant but only in a minor way. These isotopic and STATSGO data suggest that C_4 production is favored by both high temperatures during the growing season and late growing season precipitation. High temperature during early spring, however, may favor C_3 species. These relationships are quite different than those produced some time ago based on floristic composition. Comparisons of prairie relicts and adjacent forests on the Loess Hills (e.g., Newton Hills, S.D.) also document that successional changes from prairies to forests have occurred and are continuing today. Detailed analyses at Rockefeller prairie show that seemingly intact prairie systems are being shifted to forbs, as shown isotopically, apparently because of management.

Land Use and SOM: We have completed the soil fractionation and stable isotopic analyses of soil cores through the profile (to 100 cm) from control prairie, various land use, and various CRP type systems in our test site in Kansas. Figure 1 summarizes much of this isotopic information and clearly shows a good mass balance, the large turnover of carbon associated with agriculture but that this turnover is a function of depth in the profile as well as SOM fraction. SOM in coarse clay particles are the most recalcitrant and turnover decreases with depth in the profile. Most of the 14C dating has now been done and mean residence times confirm our interpretations based on stable isotopes and should allow us to derive good estimates of rates of turnover. We have also begun to interpret the dynamics of this turnover. Lignin, believed to be responsible for reclacitrant SOM, changes in isotopic composition during mineralization. But, importantly, its isotopic value approaches that of the SOM in which it is decomposing. This suggests that the basic lignin structure is being remodeled, perhaps by action of microbes on exposed functional groups of these complex molecules.

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Nov. 18, 1994. Integration of land cover classes, NDVI, STATSGO C_3 and C_4 data, and stable isotopes in assessing climate change in the Great Plains. Dept. of Ecology, Univ. of Toronto, Toronto, Can.

Other products:

Land cover classification and related AVHRR and grassland composition data are available in digital form.

Student participation:

Donovan DeJong 75%; Joel Vander Kooi; 20%; Jon Outland 25%; Chris Skaar 25%; Gretchen Green 10%; Nathan Skalsky 25%; Scott Moeller 10%.

Table 1. Seasonal land cover classes fromthe Great Plains, labels and areal extents, and C_4 composition expressed as the potential contribution to production during normal years derived drom the STATSGO data base.

Class	Label	km²/Class	C_4 Grass	Percent Total
65	Bluestem, Indiangrass, Switchgrass	46701	79	70
35	Bluestem, Grama, Wheatgrass, Small Grains	78304	72	63
59	Wheatgrass, Blue Grama, Needleandthread	107011	51	44
61	Wheatgrass, Blue Grama,Needleandthread, Big Sage	124024	39	34
56	Wheatgrass, Needlegrass, Needleandthread	115682	29	26
64	Wheatgrass, Needlegrass, Needleandthread	58920	45	39
75	Greasewood, Sage, Wheatgrass, Needleandthread	30641	37	32
80	Blue Grama, Buffalograss, Big Sage, Saltbush	78243	80	71
57	Bluestem, Blue Grama	13298	79	73
58	Blue Grama Wheatgrass, Buffalograss	14066	84	73
76	sand Sage, Blue Grama, Wheatgrass, Buffalograss	37678	97	83
81	Sand Sage, Oak, Blue Grama, Buffalograss	48085	94	82
86	Bluestem, Sand Sage, Blue Grama, Oak, Juniper	56103	94	83

Table 2. Multiple regression analysis of the effect of climate and soil variables on the proportional contribution of species to the production of native prairie sites across the Great Plains of North America. Input data in the analysis include isotopic information from approximately 75 native prairie sites and biweekly climate data gridded across the Great Plains. Variable included are those which were generally statistically significanct in analyses of isotopic and STATSGO data with climate or soil variables.

A horizon

Variable	Coefficient	p value
Intercept	-39.179	<.0001
Low Temp for April	-.021	.8638
Precipitation for July	.718	<.0001
High Temperature for Growing Season	.643	<.0001
%Sand	-.001	.8886

Positive Horizon

Variable	Coefficient	p value
Intercept	-39.701	<.0001
Low Temp for April	-.080	.5389
Precipitation for July	.840	<.0001
High Temperature for Growing Season	.685	<.0001
%Sand	-.011	.1770

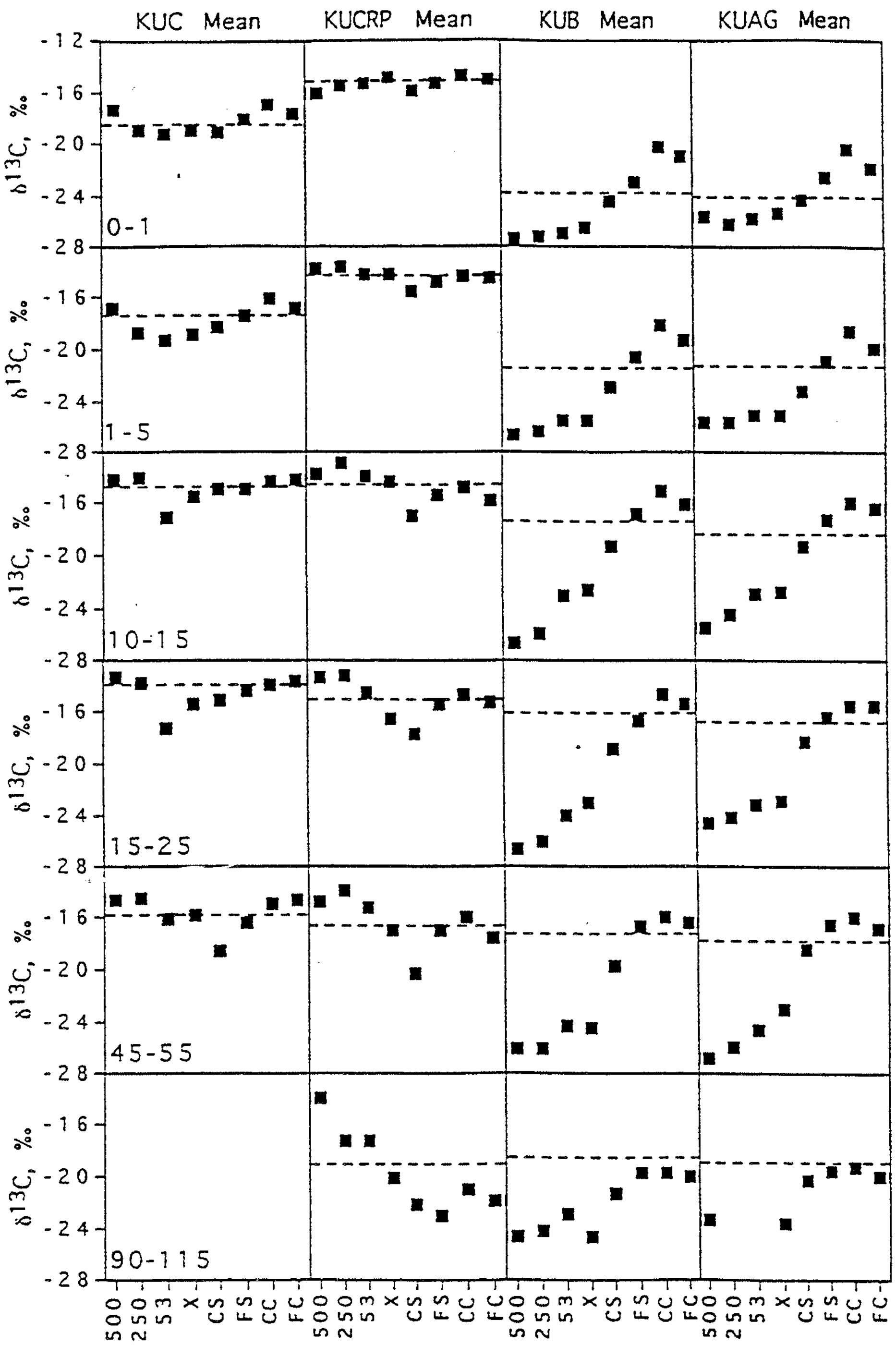

Figure 1. Stable isotopic composition (means of 4 replicates, S.E. smaller than the symbol) as a function of depth through the profile and particle size/density fractions. Categories are light fractions that pass through mesh sizes of 500, 250, 53 microns and a heavier component "X" from these light fractions and the heavy fractions of coarse silt =CS, fine silt = FS, coarse clay =CC, and fine clay =FC. Note the departures of individual fractions from the bulk soil by the dashed lines, indicating that the systems are not in steady state. KUC = Rockefeller Prairie Control, CRP = conservation reserve program analogue, B = long term brome after agriculture, AG = normal agricultural practice since prairie was broken.

Climate Change in the Midcontinent of North America

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University of North Dakota

Objectives: This research critically tests use of the geothermal gradient as a tool for studying climate change on temporal scales of decades to centuries and applies the method in a comparison of the calculated ground-surface-temperature history with the air temperature record along a 2000 km north-south transect in the midcontinent of North America. The theoretical basis for this project is that temporal changes in the average surface temperature cause transient perturbations in the geothermal gradient that may be analyzed to determine the ground-surface-temperature history. Climatic zones along a north-south transect in the midcontinent of North America vary systematically with latitude so that any climate change, either warming or cooling, should be observable as a shift of the zones along the transect. In theory, the amplitude of any change also should vary systematically with latitude. Specifically, climate simulations of global warming due to a doubling of CO_2 predict that the amplitude of warming would be greater near the poles and lesser near the equator (Hansen et al. 1988; Mitchell et al. 1990; Bretherton et al. 1990). Thus, if the predicted warming is occurring, this midcontinent transect offers a favorable study area for detecting the signal. However, direct correlation between the ground-surface-temperature history, as calculated from existing geothermal gradient data, and the historical air temperature record has not been tested. Our objectives are to test and evaluate the relationship between the ground temperature record and the air temperature record and to apply the results in an analysis of climate change in the midcontinent of North America.

Products: (1) An understanding of the relationship between the ground surface temperature and the air temperature over a complete annual cycle. (2) A comparison of the climate changes determined by analysis of air temperatures and borehole temperatures. (3) An analysis of climate change in the midcontinent of North America during the past several centuries. (4) A detailed profile of the climate histories over the instrumented period at our three climate station-borehole sites.

Approach: To investigate century-scale climate change, we are performing inversions on t-z profiles from 45 existing boreholes that were drilled and completed specifically for heat flow research in the Great Plains province between 1979 and 1990 (Gosnold, 1990). To investigate decadal sensitivity of the borehole data, we are remeasuring t-z profiles in all existing boreholes drilled between 1979 and 1984 and are comparing the results of inversions of the original and new t-z profiles. The computational method uses a least-squares inversion of the temperature-depth (t-z) profile to calculate a ground surface temperature (GST) history at the borehole site (Shen et al, 1995, 1992). The results of the inversions are essentially change from the long-term temperature mean; that is, the ground surface temperature that would be seen by the borehole in a steady-state condition where no climate change has occurred.

To examine air-ground coupling in conjunction with inversion of t-z profiles, we drilled three boreholes at carefully selected locations and installed automated weather stations and subsurface temperature monitoring instruments on the sites. Further investigation of air-ground coupling uses soil temperature and climate data available through a network of automated climate stations operated by the Regional Weather Information Center at the University of North Dakota (RWIC), the High Plains Climate Center at the University of Nebraska - Lincoln, (HPCC), and the Microclimate Research Station operated by North Dakota State University in Fargo. To test the geographic coverage of individual boreholes, we are evaluating the corresondence between our borehole climate stations and all climate stations within a 250 km radius of the borehole sites.

Results to Date: We have performed inversions on 24 existing borehole t-z profiles in addition to the three boreholes we drilled for this project. We tested the correlation with latitude for the calculated temperature increases for the 27 sites (Figure 1) and found that the 95 percent confidence limits on the correlation coefficient lie between 0.48 and 0.85. Our conclusion at this time is that the borehole data show a climate change that correlates with latitude as has been predicted by greenhouse gas warming scenarios.

We have remeasured t-z profiles in 4 holes in Nebraska, 9 holes in South Dakota, and 3 holes in North Dakota. The Nebraska holes were drilled and logged initially in 1980, and comparison of the 1995 and 1980 data revealed that the ground surface has warmed by 0.2 K in the past 15 years. The South Dakota sites were drilled and logged initially in 1990 and there was no significant difference between the inversions of the 1990 and 1995 logs. The 3 sites in North Dakota were drilled in 1983 and logged initially in 1984. All 3 showed ground warming of 0.4 K during the past 11 years.

We have drilled heat flow holes and installed automated climate stations at three sites that meet our strict criteria for borehole sites for paleoclimate studies. The localities in Texas, South Dakota and Manitoba are described in detail in our 1993 Progress Report. The criteria are: absence of microclimatic disturbances due to surface topography, no land use changes, shale bedrock, no potential for vertical ground water flow, and no terrain effect on the geothermal gradient. The stations record daily observations of: air temperature, relative humidity, incident and reflected radiation, snow depth (South Dakota and Manitoba sites only), wind speed and direction, and soil temperatures at 0, 1, 10, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10000 cm depths.

Thermal conductivities measured on core samples from the three sites are important with respect to the objectives of this project and with respect to the interpretation of heat flow data from boreholes in shale in general. Measuring shale thermal conductivities has been problematical for several reasons. First, unless special handling is employed, the core samples will rapidly desiccate and begin to change thermal conductivity within minutes after they are removed from the core barrel. Second, shale samples are typically soft and tend to fall apart in a divided-bar thermal conductivity apparatus. Third, few core samples of shales have ever been available for measurement. Consequently, virtually all published heat flow values from boreholes in shale have been based on estimated or inaccurately measured thermal conductivities.

Our Texas site provided a unique opportunity to address this general problem due to the close proximity of the Geothermal Laboratory at Southern Methodist University. At the SMU laboratory, we were able to measured thermal conductivity on the carefully preserved samples of the Eagleford Shale using three different techniques, i.e., a divided-bar, a QTM, and a half-space needle probe. The measured thermal conductivities in W/m/K are as follows:

Depth (m)	NEEDLE PROBE	DIVIDED BAR	QTM
31.0-32.6 m	0.67	-	1.05
57.0-58.5 m	0.72	0.68	0.81
79.9-81.4 m	0.72	0.76, 0.70	1.00
104.2-105.8 m	0.74	0.87	0.89

The agreement between the needle probe and divided bar results on the Eagleford Shale indicated that the needle probe, which is portable and battery powered, would be suitable for use in the field. Therefore, we used the half-space needle probe for Pierre Shale samples from the South Dakota and Manitoba sites. The mean thermal conductivity of 60 measurements spaced over 240 m at 40 m intervals on the Odonah member of the Pierre Shale in Manitoba is 1.2 ± 0.2 W/m/K. The mean for 60 measurements on the Pierre Shale at Wall, South Dakota is 1.9 ± 0.25 W/m/K a5 50 m and 2.2 ± 0.25 W/m/K at 101 m. Samples at 200 m were too fragile to measure. Currently, we are conducting grain size and compositional analysis of the samples from all sites.

Our analysis of ground-air coupling has produced significant results through numerical modeling and through analysis of soil and air temperature data from RWIC, HPCC and the NDSU Microclimate Research Station. Our computer models test ground-air coupling by using the historical air temperature data to drive the subsurface thermal regime. The results of the models, which are temperature-depth profiles that would obtain under various coupling conditions, were compared to measured temperature-depth profiles from Minot, North Dakota, Wall, South Dakota and Valentine, Nebraska. The modeling exercise provides three estimates of climate change: the first is the historical air temperature record, the second derives from numerical inversion of the model result and the third derives from numerical inversion of actual borehole data. The results of models assuming 1:1 ground air coupling are given in Table 1.

TABLE 1. Comparison of temperature changes observed at climate stations, borehole models assuming 1:1 ground-air coupling, and actual borehole data.

LOCATION	AIR TEMPERATURE dT/100 y	MODEL INVERSION dT	DATA INVERSION dT
NORTH DAKOTA	1.4 (0.138)	0.72	1.75 (4)
SOUTH DAKOTA	0.4 (0.013)	0.47	1.43 (4)
NEBRASKA	0.4 (0.024)	0.28	0.60 (3)

The numbers in parentheses under the air temperature column are the values of r^2 for the linear least squares regression. The numbers in parentheses in the data inversion column give the number of borehole profiles used and the values are averages. The low correlation coefficients for changes in air temperature result from the high interannual variability of air temperatures and emphasize the statistical uncertainty in analyzing climate data. Since the ground filters the high frequency signals and retains only the long-term temperature changes, the second column, Model Inversion, represents a more accurate determination of change in air temperature over the past century. The correlation of temperature change with latitude appears distinct; however, three samples are insufficient to test this analytically. The most important result of this modelling exercise is that the actual borehole data record significantly larger temperature increases than are seen in either of the other two methods.

Following the above tests, we began analyzing soil and air temperature data available from the HPCC, RWIC and CDIAC FTP sites. The analyses suggested that the difference between the borehole data and the models was that the models did not account for seasonal snow cover or latent heat released during freezing of soil moisture. Subsequently, we developed models that include seasonal snow cover and latent heat but did not achieve better correspondence with the warming trends seen in the borehole data. The insulating effects of snow cover and the latent heat released by freezing soil moisture cause ground temperatures to be warmer than air temperatures such that the difference between the two correlates with mean temperature and, in the midcontinent, with latitude. However, this difference could not cause a secular warming trend in the GST unless its effect also increased with time. We doubt that such a trend could be largely controlled by snow cover since Spring snow cover has decreased for the past 20 years in the Northern Hemisphere (Groisman, Karl, and Knight (1994). This led us to suspect that soil moisture may be a key factor in determining ground surface temperatures. In fact, precipitation data from CDIAC (Groisman and Easterling, 1994 shows that annual precipitation has increased by more than 100 mm in the past 50 years in the Northcentral United States and Canada. At this time we tentatively conclude that a secular increase in precipitation in northerly latitudes where the ground freezes for significant periods has caused a secular increase in ground surface temperatures. This causes borehole temperatures in those regions to record greater warming than has actually occurred. This is a significant result since only 15 of the 362 borehole sites in North America that have been analyzed for GST histories lie in regions that do not experience seasonal ground freezing.

Manuscripts in preparation and submitted:

The geothermal gradient and climate change, in preparation for submission to Science.

Presentations:

The geothermal gradient and climate change, International Workshop on Borehole Temperatures and Climate Change, Prague, Czech Republic, 1995.

Analysis of the geothermal gradient as a method of paleoclimate reconstruction, American Geophysical Union Fall Meeting, 1994.

Heat flow data from core holes at the Manson Impact Site, Geological Society of America Annual Meeting, 1994.

Interpretation of Temperature-depth Logs from Boreholes in Manitoba and Saskatchewan, GAC - MAC Annual Meeting, Waterloo, ONT, 1994.

Student participation:

William Schmidt 100%, Paul Abell 100%, Tim Freije 25%, Steve Smith 25%.

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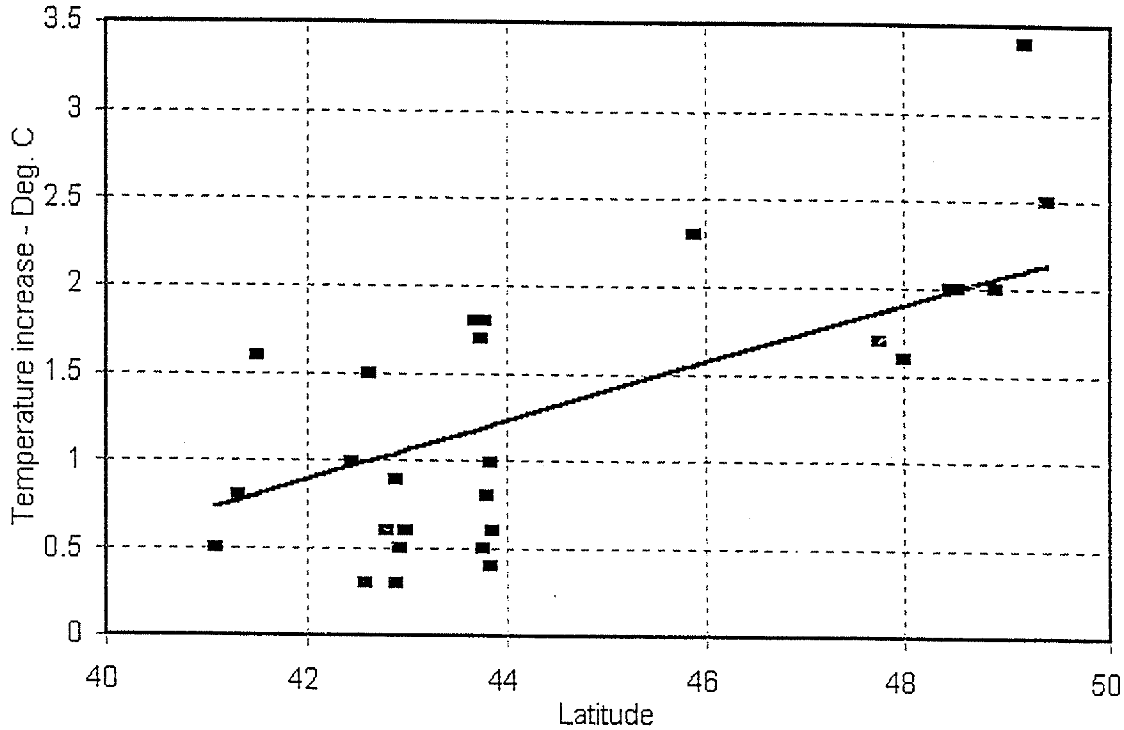
GST history vs. latitude



Satellite Observation of Lake Ice as a Robust Indicator of Regional Climate Change

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Objective: The exploration of lake ice breakup as a spatially explicit climate indicator in the mid- to high latitude regions in late winter/early spring, the spatiotemporal "region" where temperature increases due to enhanced greenhouse warming are often predicted to be greatest. Realization of this objective is being effected via (1) satellite image analysis of lake ice breakup, (2) geostatistical and trend analysis of lake ice breakup patterns, and (3) implementation of a numerical thermodynamic lake ice model to simulate, via detailed sensitivity analyses, lake ice phenology under alternative climate scenarios.

Products: (1) Assemblage of relevant archival satellite (primarily GOES-VISSR) image data for a latitudinal transect (60°N, 105°W to 40°N, 85°W) including 81 large inland lakes and reservoirs in Wisconsin, Northern Michigan, Minnesota, North and South Dakota, and portions of Manitoba, Ontario, and Saskatchewan, Canada (Figure 1). (2) Development of a methodology for reliably and systematically determining ice-off dates for those lakes large enough to be reliably resolved by the visible band (0.54-0.70 μm) of the GOES-VISSR, yet small enough to have a temporally distinct breakup date. (3) Satellite-derived ice-off dates for the 81 study lakes from 1980-1994, the period over which suitable metsat data were acquired and archived. (4) Provision of an initial basis for understanding both the climatic causes and limnological ramifications of observed variation in ice temporal dynamics and distribution. (5) Typification of the response of lake ice in the region given alternative meteorological forcing.

Approach: We are analyzing patterns of ice breakup on the resolvable rapid transition lakes in the study area (Figure 1) via satellite image analysis of archival metsat scenes. This analysis is based predominantly on both visual and automated classification of more than 2000 GOES and AVHRR images of the region. The assembly, preprocessing, and analysis of this huge (> 8 GB) data set has been an important focus of the study to date. Our earlier work suggested both the feasibility of using the AVHRR to determine the date of lake ice breakup as well as the strong correlation of the AVHRR-derived ice-off date with local air temperature (Wynne and Lillesand 1993), and data from this sensor continues to be a supplemental data source. However, we have relied principally on comparatively lowcost digital GOES data from the national archive (held by the Space Science and Engineering Center of the University of Wisconsin-Madison).

Our examination of the relationships among the spatiotemporal variability in climate, lake morphology, and lake ice phenology is based upon both statistical analyses (e.g., Wynne et al. 1995) and process-based modeling (e.g., Vavrus and Wynne 1994, Vavrus et al. 1995). The former is predicated on (1) determining the extent to which the response of a single lake can serve as a regional climate proxy, (2) assessing the presence or absence of any trends in the data both in space and time, and (3) attributing any observed trend in time and/or space to attendant causes (in concert with the process-modeling component).

We found temporal coherence, the "degree to which different locations within a region behave similarly through time" (Magnuson et al. 1990) to be a useful means of assessing the degree to which one can generalize site-specific findings to the surrounding region. We calculated the temporal coherence of ice-off dates (1987-1994) between each lake-pair by taking the product-moment correlation between their 8 year time series (1987-1994) of ice-off dates. The 62 lakes used in this analysis generated 1891 lake-pairs (62 x 61 ÷ 2). Ice breakup dates do not appear to be autocorrelated, thus it was unnecessary to lag the time series and re-compute coherence. We determined the significance of the determinants of temporal coherence of lake ice-off dates as well as the determinants of mean lake ice-off dates via a randomization test written in Matlab™. For the coherence analysis we randomly selected completely independent lake-pairs, such that any lake represented in a particular lake-pair was not present in any other lake-pair. While this would not completely remove any possible spatial dependence among observations, it could help to reduce considerably dependence among correlation values (Wynne et al. 1995).

An important goal of this study is the assessment of any trend toward earlier or later ice-off dates during the study period. As noted, ice-off dates do not seem to be serially autocorrelated. However, the spatial distribution of the mean ice-off date is far from stationary. In our ongoing analysis, we first remove as much of the spatial pattern as possible through the use of appropriate explanatory variables. This then affords us the possibility to examine the data set for temporal trends.

Process-based modeling provides a rigorous means to determine the climate sensitivity of lake ice, as well as how this sensitivity may be tempered by lake morphology. We have utilized the numerical thermodynamic lake ice model LIMNOS (Lake Ice Model Numerical Operational Simulation) described by Vavrus et al. (1995). The input variables required to drive LIMNOS are mean lake depth, air temperature and moisture, wind speed, solar radiation, snowfall, and cloudiness. These variables (excepting cloudiness) can be altered systematically to determine the sensitivity of any lake ice property (thickness, ice formation date, ice breakup date, etc.) to any type of climate change and to variations of lake depth. Hourly data obtained from the NOAA National Climatic Data Center Solar and Meteorological Surface Observation Network (SAMSON) from 1960-1990 were used to drive LIMNOS. Subsequent to exploration and testing in this historical context, Vavrus et al. (1995) performed a detailed sensitivity analysis to quantify the effects of altered meteorological forcing on the thermodynamics of lake ice.

Results to Date:

Assembly, Processing, and Analysis of Archival Satellite Data

As noted in the previous section, the assembly, processing, and analysis of the enormous (> 8 GB) satellite digital data set has been an important focus of the study to date. We have now completed the assessment of all 1830 GOES-VISSR scenes. These images were acquired at or near 19:00:00 coordinated universal time (UTC) on a daily basis from March 1 to June 30, 1980-1994. With the knowledge that these data are important deliverables in and of themselves (and will be an important archive beyond our project lifetime), we have paid careful attention to both appropriate preprocessing and metadata. To the latter end, we are using the Borland Paradox™ relational database to store both reduced browse imagery and relevant metadata. Paradox fields for the GOES data set include, for example, the original archival file name, Erdas file name, name of the destriped image, sensor source, date, day number, UTC time, number of rows and columns, number of bands, byte order, banding angle, etc. We are fortunate to have a CD-ROM recorder in-house, and plan to make CD-ROMs of the project metadata as one of our final products.

Preprocessing of the GOES digital data presents problems not encountered with the AVHRR data set, notably extensive striping (caused by the differences in gain among the sensor's eight photomultipliers in addition to substantive quantization error due to the 6-bit radiometric resolution). In this regard, we are fortunate to have collaborated with Dr. Frank Scarpace (UW-Madison Environmental Remote Sensing Center), who has tailored his fast Fourier transform (notch) filtering software for the needs of this project (Wynne et al. 1995).

Visual interpretation was performed in a temporal context, in which ice-off dates were determined relative to ice conditions on proximate days. Major constraints were cloud cover, the poor spatial and spectral resolution of the GOES-VISSR, and the difficulty in distinguishing bare ice from open water.

Comparison to available ground-derived ice breakup dates revealed a mean absolute difference of 3.2 days and a mean difference of -0.4 days (Rodman et al. 1995).

Determinants of Temporal Coherence of Ice Breakup Dates

The remotely-sensed ice breakup dates from 1987-1994 for 62 of our study lakes[3] were analyzed to assess preliminarily determinants of the mean date of lake ice breakup and to identify determinants of temporal coherence of lake ice breakup (Wynne et al. 1995). The mean thaw date was day number 116 (given January 1 is day number 1 in a particular year). The range was from day number 80 (Lake Geneva, Wisconsin) to day number 170 (Etawney Lake, Manitoba). Correlations among the mean breakup date and the explanatory variables (surface area, maximum depth, surface area/maximum depth ratio, latitude, longitude, and elevation) revealed that only latitude ($r = 0.9603$, Figure 2) and surface area ($r = 0.4535$) were significant at $p \leq 0.05$. Latitude and surface area were significantly correlated ($r = 0.4173$) (Wynne et al. 1995).

The temporal coherence of ice-off dates between each pair of lakes was calculated by taking the product-moment correlation between their 8 year time series (1987-1994) of ice-off dates. The mean coherence was 0.4493, with values ranging from -0.8751 to 0.9996. There is a general lack of strong temporal coherence among lakes, implying that no lake within this study area is representative of the entire region. The significant ($p \leq 0.05$) correlates of the temporal coherence of ice-off dates were the difference in mean ice-off date (-0.4948) and the difference in latitude ($r = -0.5129$), themselves significantly correlated ($r = 0.8926$). The differences in surface area, maximum depth, surface area/maximum depth ratio, longitude, and elevation were not significant. The general lack of strong temporal coherence between lakes and the significant correlation between coherence and the mean ice-off date are further confirmation that ice-off dates for different lakes may be reflections of (and indicators for) different periods of meteorological forcing. Temporal coherence of ice breakup dates may prove to be one important means of determining the subset of lakes that can serve as proxies for each other and for the late winter and early spring climate in a particular region (Wynne et al. 1995).

Adaptation and Application of Climate-Ice Physics Model

LIMNOS simulates the growth and decay of lake ice by time-integrating the vertical heat conduction equations for layers of ice and snow. An energy balance at the ice and snow surfaces is assumed, such that the sum of incoming net shortwave and longwave radiative fluxes as well as sensible and latent turbulent heat fluxes are balanced by vertical heat conduction through the ice and snow layers. Implementation of this model for Lake Mendota using hourly SAMSON data from 1960-1990 produced quite realistic ice freeze (RMSE of 3.5 days) and thaw (RMSE of 5.4 days) dates (Vavrus et al. 1995). These errors are much smaller than the range of natural variability of both ice-on ($\sigma = 10.0$ days) and ice-off ($\sigma = 11.8$ days) dates during this period. Extensive sensitivity tests of this model reveal (1) the ice-off date is more sensitive than the ice-on date to air temperature changes (Figure 3), (2) the sensitivity of both ice-on and ice-off dates is greater for climatic warming than cooling (Figure 3), (3) increased snowfall produces a monotonic delay in the simulated breakup date (Figure 4), and (4) decreased snowfall leads to a non-linear acceleration of ice decay (Figure 4).(Vavrus et al. 1995).

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Student Participation

Randolph H. Wynne, Graduate Research Assistant, 50%.
Daniel C. Rodman, Undergraduate Project Assistant, 20%.

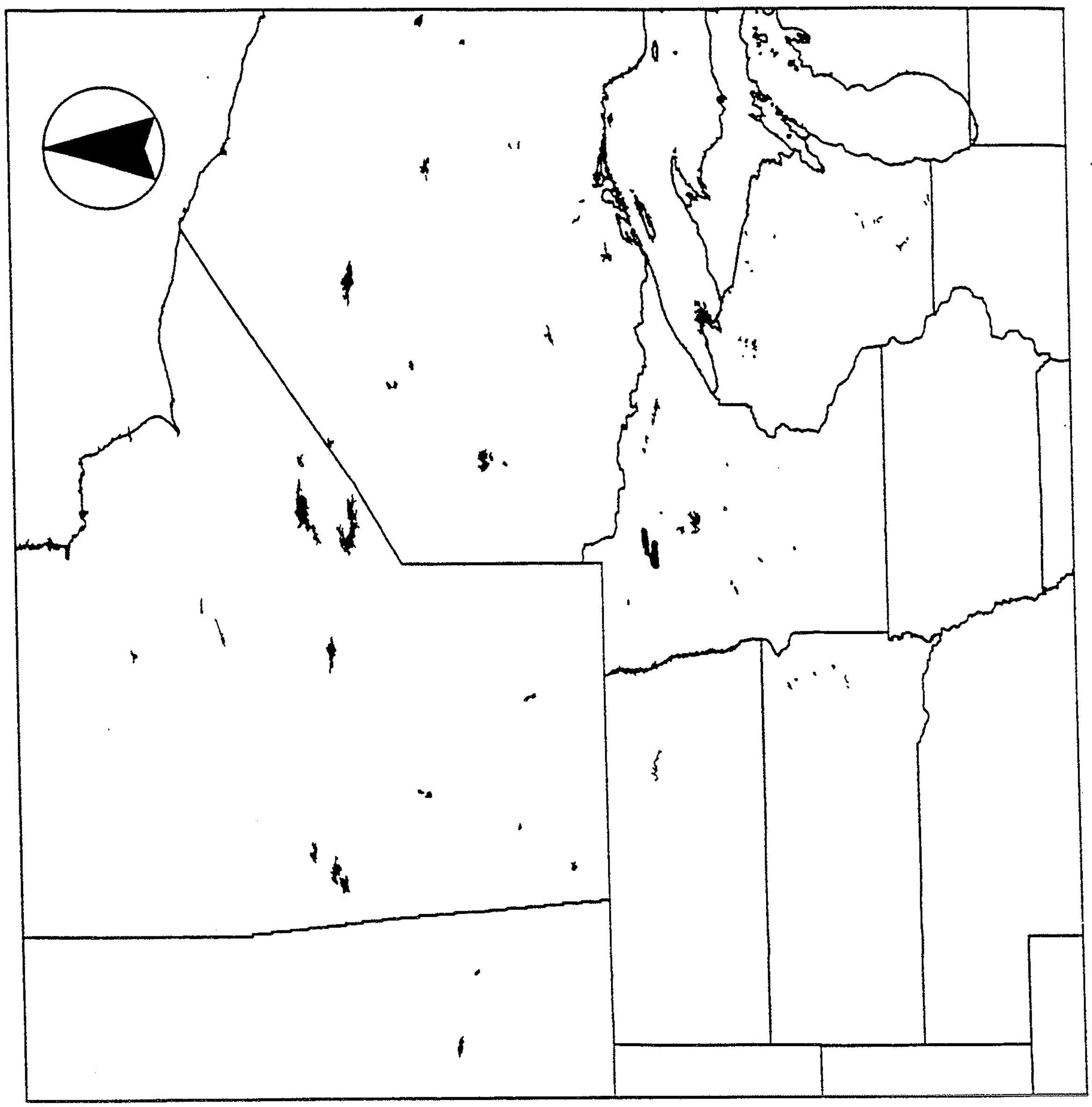

Figure 1. Map of study area showing general locations of the 81 study lakes and reservoirs. Map source: Digital Chart of the World.

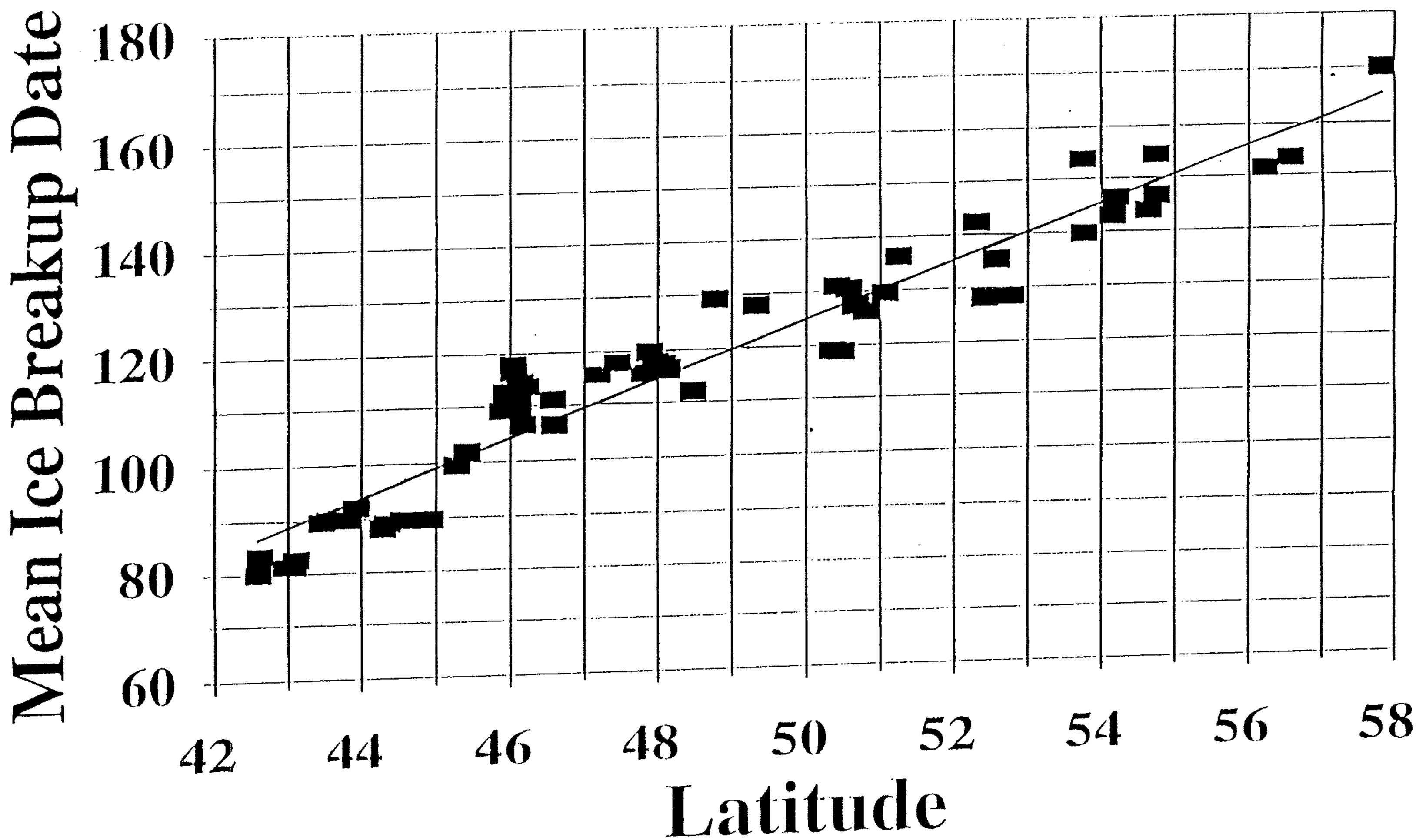

Figure 2. Satellite-derived mean ice breakup date (1987-1994) as a function of latitude for our study lakes. This relationship is highly significant, with R^2 = 92%, p = 0, and standard error = 6.4 days (Wynne et al. 1995).

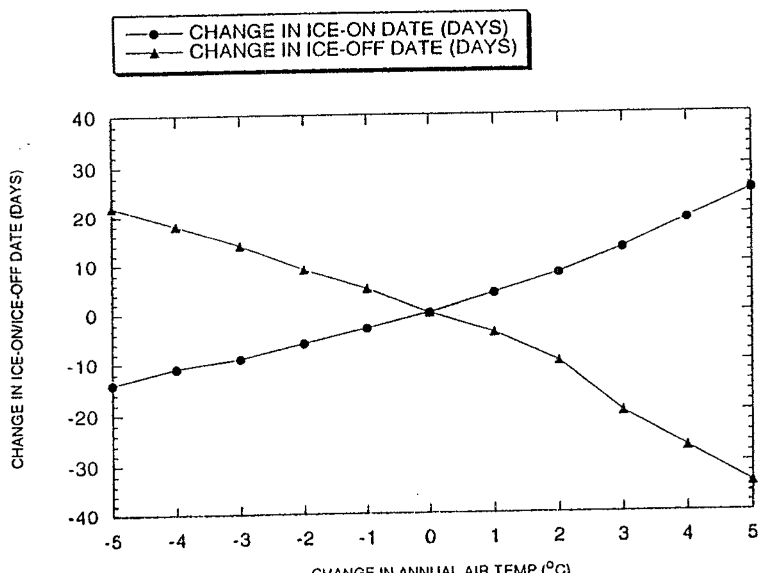

Figure 3. Simulated change in the dates of ice formation and breakup for Lake Mendota due to changes in mean annual air temperature. Note the greater sensitivity of the ice-off date (Vavrus et al. 1995).

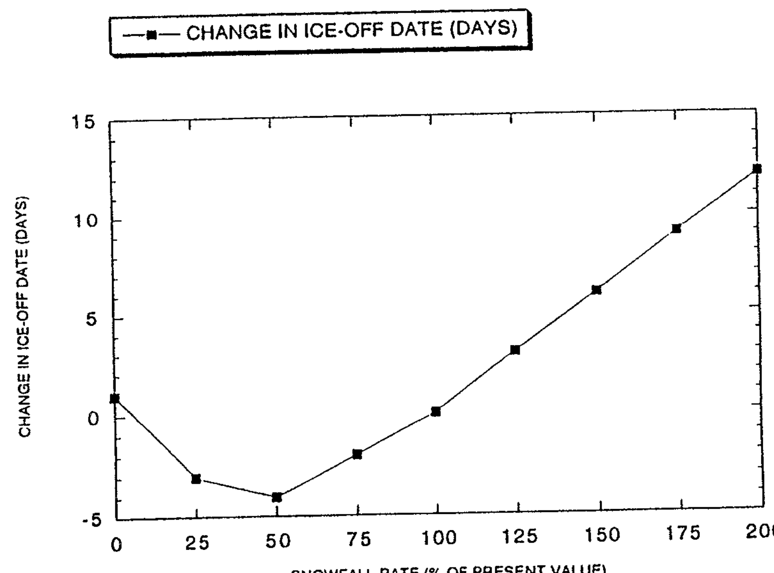

Figure 4. Effect of snowfall rate on the simulated ice-off date of Lake Mendota. When snowfall is reduced more than 50%, the increased conductive heat loss associated with less snow cover mitigates the enhanced surface abiation that accompanies a thinner, less persistent snow pack (Vavrus et al. 1995).

AUTHOR INDEX